HEAT

WOOLLCOMBE

Practical Work in Heat

FOR USE IN SCHOOLS AND COLLEGES

BY

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PREFACE

THE chief value of a scientific education consists not so much in storing the mind with a large number of facts as in the training of the powers of accurate observation and reasoning, and perhaps one of the best means of attaining this end is a course of Practical Work in Heat. Such a course not only trains the hand and eye, but the necessity for continual precaution and carefulness in manipulation makes it an excellent introduction to practical work in other branches of Physics. All schools which include Science in their curriculum have at least a Chemical Laboratory; but in many cases Physics is only taught by lectures accompanied by demonstrations by the teacher—doubtless because the cost of apparatus, if multiplied sufficiently to accommodate large classes, would be great. This is not the case with the branch of Physics treated of here. The apparatus required is inexpensive, and such as is herein described may be readily obtained or easily made from the ordinary stock of a Chemical Laboratory.

The average number of students in the classes under the author's charge is twenty-two. In practical work they are

arranged in pairs, and at the beginning of the hour each
set receives a sheet of instructions in manuscript, treating
of the particular experiment allotted to it.   These in-
structions now take the more permanent form of print,
in the hope that they may be more generally useful.
The above method prevents the loss of time which would
ensue if each experiment had to be explained *viva voce*.
With the help of the instructions work can be begun
at once, and ample time is afforded for the teacher to
go round and give any further explanation or help in
manipulation that may be needed, the lectures being
arranged so as always to be in advance of the practical
work.   After the experiment is completed and the
result passed by the teacher, each student is required
to enter into a note-book, kept especially for the
purpose,

> (*a*) The enunciation of the experiment.
>
> (*b*) A description of the method, either copied from
>   the sheet of instructions, or, in the case of
>   older students, in their own words.
>
> (*c*) A figure, carefully drawn, of the apparatus used.
>
> (*d*) Their results in a properly tabulated form.

This last is essential, as, unless it is insisted on, a
great deal of the good effect of the work is lost.

Most of the experiments described are within the
range of boys of fourteen, who often obtain good
results, and it is hoped that this book may be found
useful also to those who are preparing for higher
Examinations in which the subject is required.   The

author begs to acknowledge his indebtedness chiefly to Professor Worthington's Laboratory Practice, and to the book on Heat by Mr. H. G. Madan. Mr. Madan has also kindly revised the manuscript, and made several important suggestions, which have been incorporated in the work.

CONTENTS

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LIST OF EXPERIMENTS.

Those experiments which are marked with an asterisk (*) *are suitable only for older students.*

A. THERMOMETRY.

B. EXPANSIONS.

E. RADIATION.

PRACTICAL WORK IN HEAT.

height corrected for the expansion of the scale is $h\,(1 + bt)$.

(*b*) Since the density of mercury at 0° C is $1 + \delta t$ times greater than its density at $t°$, where δ is the mean coefficient of absolute expansion of mercury between 0° and $t°$, the column of mercury at 0° representing the atmospheric pressure would be $1 + \delta t$ times shorter than the column at $t°$. Our reading therefore is too high, and the height $h\,(1 + bt)$ corrected for the expansion of the mercury is

$$\frac{h\,(1 + bt)}{1 + \delta t} = h\,(1 + bt)\,(1 + \delta t)^{-1} = h\,(1 - [\delta - b]\,t), \text{ nearly.}$$

If the scale is of brass $b = \cdot 0000189$, and taking the coefficient of expansion of mercury δ to be $\cdot 00018$, this expression becomes

$$h\,(1 - \cdot 00016t).$$

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[1] Or of glass if the scale is etched on the glass tube itself.

PRACTICAL WORK IN HEAT.

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A. THERMOMETRY.

1. Correction for barometer readings.

The standard barometer is graduated when both the scale and the mercury are at $0°C$, so that we ought always to reduce our reading, h, of the barometer at the temperature, t, of the room to what it would be if the scale and the mercury were at $0°C$.

(a) Each unit length of the scale at $t°$ is longer than it would be at $0°$ by $1 + bt$, where b is the coefficient of linear expansion of the metal scale[1]. Our reading h is therefore too low, and the height corrected for the expansion of the scale is $h(1 + bt)$.

(b) Since the density of mercury at $0°C$ is $1 + \delta t$ times greater than its density at $t°$, where δ is the mean coefficient of absolute expansion of mercury between $0°$ and $t°$, the column of mercury at $0°$ representing the atmospheric pressure would be $1 + \delta t$ times shorter than the column at $t°$. Our reading therefore is too high, and the height $h(1 + bt)$ corrected for the expansion of the mercury is

$$\frac{h(1 + bt)}{1 + \delta t} = h(1 + bt)(1 + \delta t)^{-1} = h(1 - [\delta - b]t), \text{ nearly.}$$

If the scale is of brass $b = ·0000189$, and taking the coefficient of expansion of mercury δ to be $·00018$, this expression becomes

$$h(1 - ·00016t).$$

---

[1] Or of glass if the scale is etched on the glass tube itself.

(*c*) There are two other corrections to be made: one for the index error, which is merely the mistake of the maker; the other for capillarity, which depends on the diameter of the tube. These two corrections are made once for all for a given barometer and must be added to all reduced observations.

Example. On a day, when the temperature was 15°, the height of the barometer was 754·3^{mm}. Reduce this reading to 0°.

The reduced height is 754·3 [1 − ·00016 × 15] = 752·49

$$\text{Capillarity and index error} = \quad \text{·24}$$

$$\text{Corrected height} = 752\text{·}73$$

2. Correction for thermometer readings.

When the whole of the thread of mercury in a thermometer is not immersed in the substance whose temperature we are measuring, the thermometer reading is somewhat too low, and we must apply a correction to it to give us the true temperature of the substance.

Suppose $T°$ the true temperature of the substance,

$t°$ the temperature indicated by the thermometer,

$t°'$ the mean temperature of the air near the thermometer,

l the length of the projecting thread.

If the whole of the mercury were at the temperature T, the length l would become $l[1 + \Delta(T−t')]$, where Δ is the coefficient of relative expansion of mercury. If n is the number of degrees in unit length, the number of degrees in the length l is nl, or N suppose. Therefore, at $T°$, N would become $N[1 + \Delta(T−t')]$, that is, the thermometer reading would be increased by $N\Delta(T−t')$,

$$\therefore \quad T = t + N\Delta(T−t'),$$

or

$$T = \frac{t − N\Delta t'}{1 − N\Delta} = (t − N\Delta t')(1 − N\Delta)^{-1} = t + N\Delta(t−t'), \text{ nearly,}$$

where $\qquad\qquad \Delta = ·000155.$

Example. Find the true temperature of water when a thermo-

meter, immersed up to the 20th degree, shows a temperature of 80·3°, while the temperature of the surrounding air is 16·7°.

$$T = 80·3 + 60·3 \times ·000155 (80·3 - 16·7)$$
$$= 80·89°.$$

3. Comparison of two thermometers.

It is often convenient and sometimes necessary to use two thermometers in an experiment, and, as mercury thermometers seldom exactly agree, it is important to compare one with the other.

Apparatus. Two thermometers: Beaker: Sand-bath: Retort-stand and Clamp: Bunsen Burner: Curve-paper [2].

Experiment. Tie the two thermometers together and support them by the clamp so that they dip vertically into a beaker of water placed on a sand-bath. Heat the water gradually, keeping the whole of it well stirred [3] continually. About every five degrees rise of temperature take the readings of each thermometer [4]. Enter the corresponding temperatures in two adjacent columns. Continue taking readings until the water boils.

Plot a curve of your results as follows:—Take a piece of curve paper and draw two straight lines at right angles to each other near the lower and the left-hand edges of the paper. These lines are called the axes of the curve, and the point of their intersection the origin. Along the bottom line [the line of abscissae] mark off equal spaces to represent 5°. The number of divisions on the paper to be taken to represent 5° must depend (*a*) on the number at your disposal and (*b*) on the range of temperature to be indicated. Along the left-hand vertical line [the line of ordinates] mark off equal spaces [not necessarily of the same length as before] to represent 5°. Along the horizontal line place very

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[2] See Appendix B. 9.

[3] Stirring is a most important operation where uniformity of temperature is required. A feather or a flat piece of wood does well for a stirrer.

[4] In reading a thermometer place your eye on a level with the top of the mercury thread, and always estimate to tenths of a degree. A pocket magnifying glass is useful for the purpose.

small dots at the points representing the temperatures you have read on thermometer *A*, and along the vertical line at the points representing the temperatures read on the thermometer *B*. Now mark with a very small cross the points obtained by the intersection of *imaginary* vertical lines through the temperatures of *A* with *imaginary* horizontal lines through the corresponding temperatures of *B*. Draw carefully a fine continuous line [curved or straight as the case may be] which will pass through the average run of the series of points so obtained[5]. The points along this curve represent also those which we have not determined by experiment. We can now easily find what temperature on one thermometer corresponds to a given temperature on the other. For, if we wish to know what temperature on *B* corresponds to 55·5° on *A*, draw a vertical line through the point representing this temperature on *A*, and from the point where this line intersects the curve draw a horizontal line. This will cut the vertical temperature line of *B* at the required point. Fig. 1 shows a curve obtained by comparing two given thermometers.

4. Test freezing point of a thermometer.

Apparatus. Funnel: Beaker: Thermometer: Retort-stand: Ice.

Experiment. Place the funnel in a ring of the retort-stand and under it place the beaker. Hang the thermometer with its bulb inside the funnel so that the zero is on a level with the rim. Well wash a piece of ice and with a chisel scrape off some shavings. Pack these round the thermometer in the funnel. Pour over them some distilled water and determine the lowest point to which the mercury sinks. The difference between this point and 0° will be the zero error of the thermometer.

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[5] The curve will not pass through all the points unless your observations have been perfectly exact. Some points will probably be above and some below the final curve. It is a good thing to use a piece of thin cardboard or a flexible lath as a guide when tracing the curve. When a curve is completed, always write along the top edge of the paper the experiment to which the curve refers, and along the horizontal and vertical axes the name of the measurements to which their corresponding divisions refer.
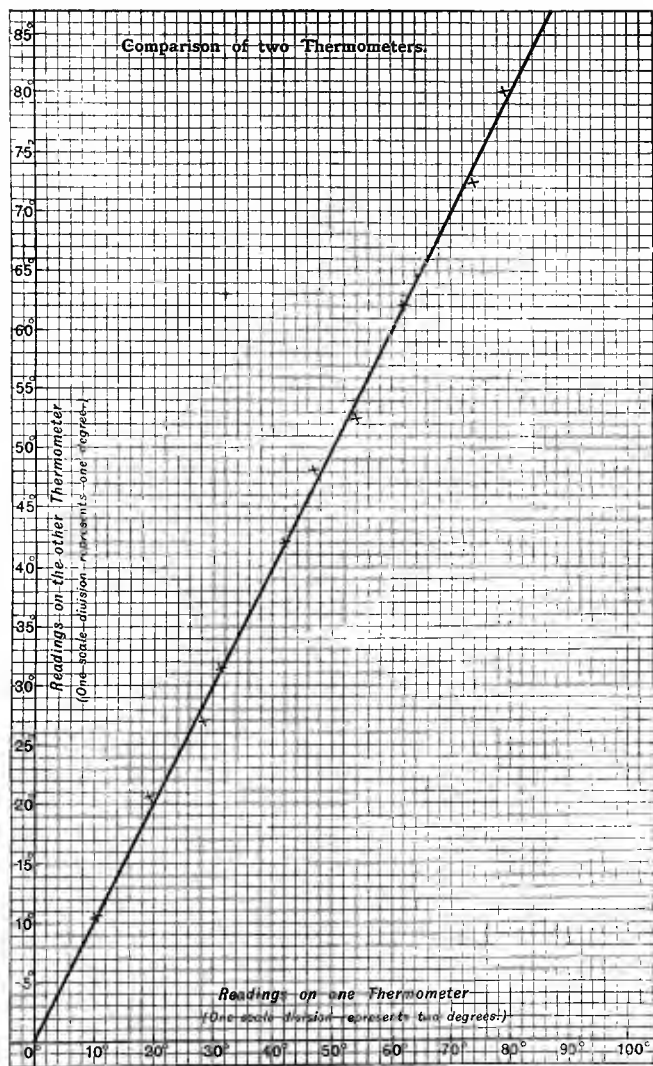
Fig. 1.

5. Test boiling point of a thermometer.

Apparatus. Flask fitted with a two-holed bung : Short elbow-tube : Thermometer : Sand-bath : Bunsen Burner.

Experiment. Fill half the flask with water. Fit the elbow-tube into one hole, the thermometer into the other hole of the bung. Arrange the thermometer so that, on placing the bung in the flask, the bulb is about 1 cm. above the surface of the water. Place the flask on the sand-bath and apply heat. When the water has boiled briskly for some time, and the thermometer has risen as far as it will, read the temperature. This gives the boiling point under the present atmospheric pressure. We must now correct for the difference between this and the standard pressure of 760^{mm}. From the table giving the boiling points under different pressures [Appendix A. 10] we find that a difference of $1°$ in the boiling point corresponds to a difference of pressure equal to 26.8^{mm}. Therefore, if $x°$ is the required correction,

$$26.8 : 760 - \text{barometric height} :: 1° : x°.$$

Example. A thermometer marks $99.3°$ as the boiling point of water when the height of the barometer is 755.5^{mm}. Find the error of the thermometer.

$$26.8 : 4.5 :: 1° : x°; \qquad \therefore \quad x = .17°, \text{ nearly.}$$

$$
\begin{array}{lcr}
\text{Thermometer reading} & = & 99.3 \\
\text{Correction} & = & .17 \\
\hline
& & 99.47 \\
\text{Error of boiling point} & = & .53 \\
\hline
& & 100.00 \\
\hline
\end{array}
$$

6. Determination of the melting point (Method 1).

Apparatus. Glass tube drawn out to a fine bore : Beaker : Test-tube : Thermometer : Sand-bath : Bunsen Burner : Paraffin-wax.

Experiment. Melt the wax in the test-tube and draw up some of the liquid into the narrow glass tube. Fuse the end and tie it to the thermometer and support vertically in a beaker

of water placed on the sand-bath. Heat the water, keeping it continually stirred. Note the temperature at which the wax begins to be transparent. Take away the burner and allow the water to cool. Note the temperature at which the wax begins to solidify. The mean of the two readings will give the melting point approximately. Lower the flame and heat very gently, so as to determine the melting point as above more accurately. Repeat this twice more and take the mean of the results as the true melting point.

Determine as above the melting points of Beeswax and Stearic Acid.

7. Determination of the melting point (Method 2).

Apparatus. Test-tube fitted with a two-holed cork : Beaker : Thermometer : Sand-bath : Retort-stand : Watch : Bunsen Burner : Paraffin-wax : Curve-paper.

Experiment. Fill the test-tube with the melted wax and fix the thermometer [6] in the cork so that it dips into the melted wax up to the 20th degree or so. Support the test-tube by a string to the retort-stand and bring up a beaker of water to immerse it completely. Heat the water till the wax is all melted. Take away the beaker, wipe the test-tube dry, and allow the wax to cool gradually. Note the temperature indicated by the thermometer every half minute until the wax has become quite solid and has cooled to about 30°. Arrange your results in a tabular form as follows :—

Times.	Temperatures.
......	......
......	......

Plot your results in a curve taking the times as abscissae and the corresponding temperatures as ordinates. As the liquid

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[6] The thermometer ought previously to be warmed carefully over a flame to prevent its breaking when placed in the melted wax.

gives out its latent heat on solidifying the temperature will for some time remain more or less stationary at this point. Therefore the curve will show two turning points. The line between them is approximately parallel to the axis of times, and, if produced, will cut the axis of temperatures at the required melting point. Compare your result with that of Experiment 6.

Determine as above the melting points of Beeswax and Stearic Acid.

*8. Determination of the melting point of an alloy.
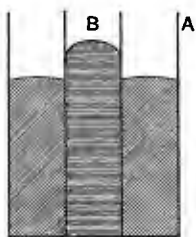
Fig. 2.

[*A* is a cylindrical vessel of sheet iron, 3 cm. in diameter, 6 cm. in height. In the middle of it is fixed a metal tube *B*, 1 cm. in diameter. Between *A* and *B* is the alloy. The tube *B* contains mercury, the level of which is just above that of the alloy.]

Apparatus (Fig. 2). Thermometer: Watch: large Bunsen Burner: Mercury: Common Solder [equal parts by mass of Lead and Tin]: Curve-paper.

Experiment. Fill the outer cavity of the apparatus about three parts full with the alloy and the inner cavity rather more than three parts full with mercury. Close the central tube with a loose cork through which a thermometer passes so that the bulb dips under the mercury. Heat this vessel up to about 220°C so as to completely melt the alloy. Take the burner away and allow the vessel to cool. Read the thermometer every minute until the alloy has become quite solid. Arrange your results in a tabular form and plot a curve as in Experiment 7, and notice the difference between the two curves. In this case there are four turning points, which is explained by supposing the alloy to consist of two distinct alloys, whose chemical compositions are different and which melt at different temperatures. After raising the temperature above the melting point of the less fusible and allowing it to cool this one solidifies, first giving out its latent heat. On cooling further the temperature is attained

at which the other component solidifies. The alloy that gives two turning points only is called the 'chemical alloy' of the two component metals.

Determine as above the melting points of the following alloys :—

> 1 part by mass of Tin and 3 parts by mass of Lead (270°)[7],
> 1 part by mass of Lead and 3 parts by mass of Tin (200°)[7].

9. Determination of the boiling point (Method 1).

[*A* is a boiling tube 3 cm. in diameter. Through the cork passes air-tight a smaller test-tube *B*, about 2 cm. in diameter, which has a hole fused in its side at *a*. Through the cork of the test-tube pass a thermometer *T* and an elbow-tube *C*, one end of which is close to the bulb of the thermometer.]

Apparatus (Fig. 3). Thermometer: Bunsen Burner: Methyl Alcohol.

Experiment. Put some methyl alcohol in the outside boiling tube and fit the apparatus together as in the figure. On boiling the liquid the vapour fills the larger vessel and passes through the hole *a* to the bottom of the inner one and then up through the tube *C*. The thermometer will rise: note the temperature indicated by it when it becomes quite stationary. This will be the boiling point of the liquid under the existing atmo-

Fig. 3.

spheric pressure. Enter the temperature and the barometric height.

Determine as above the boiling points of Turpentine and Benzol.

10. Determination of the boiling point (Method 2).

[Take a piece of glass tubing about ·5 cm. in diameter and 25 cm. in length. Clean and dry it carefully. Close one end by the blow-pipe and bend it as in the figure, making the closed limb about 7 cm., and the elbow-piece at the open end about 3 cm. in length. Introducing some

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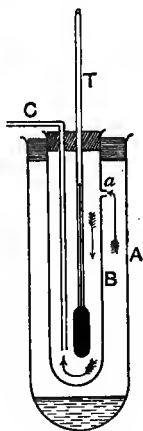
[7] These are the temperatures to which the alloys must be raised respectively.

clean dry mercury we can, by a little manipulation, fill all the tube with it excepting the short elbow-piece. Then fill the elbow-piece completely with the liquid whose boiling point we require. Close the tube with the finger, and turning it slowly over, allow about ·5 cub. cm. of the liquid to pass to the closed end. If there is an air bubble present, transfer the liquid back again to the elbow-tube, add a drop or two more and repeat the above process. Having got the liquid into the closed end free from air bubbles, we have now to get mercury out from the longer limb until its level is about 2 cm. below the top of the closed limb. This may be done by putting the tube into a beaker of water and carefully heating it. Sufficient mercury, as it rises in the longer limb, can be got rid of by a judicious jerk.]
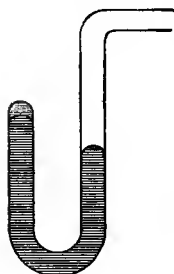
Fig. 4.

Apparatus (Fig. 4). Beaker: Thermometer: Sand-bath: Bunsen Burner.

Experiment. Support the apparatus in a beaker of cold water so that the shorter limb is completely immersed, and place a thermometer close to it. Gradually heat the water, keeping it continually stirred. The pressure of the vapour of the liquid in the tube will increase and will depress the mercury in the shorter limb. When the level of the mercury is the same in the two limbs the pressure of the vapour is equal to the atmospheric pressure. When this is the case, note the temperature by the thermometer. On taking away the burner the mercury in the right-hand limb may continue to rise for a little. If so, allow the water to cool and take another reading of the thermometer when the two columns return to the same level. Repeat this twice more, and take the mean of your readings as the boiling point of the liquid under the existing atmospheric pressure. Record both the temperature and the barometric height.

Determine as above the boiling points of Turpentine, Ether and Carbon Bisulphide.

*11. Variation of the boiling point with the strength of a saline solution.

Apparatus. A large flask fitted with a cork through which

pass a short elbow-tube and a thermometer : Sand-bath : Bunsen Burner : Crystallised Calcium Chloride : Curve-paper.

Experiment. Drop a small piece of clean coke into the flask to prevent boiling with bumping and counterpoise the flask and cork. Put about 20 grams of the salt into the flask and find exact mass of salt, m_1, added. Fill the flask about one-third full of distilled water, and arrange the thermometer with its bulb immersed in the liquid. Boil this solution and note the boiling point t_1. Weigh the flask so as to determine the mass, M_1, of the solution. Add about 20 grams more of the salt. Weigh again to determine exact mass, m_2, added. Boil and note the boiling point t_2. Weigh to determine the mass, M_2, of the solution. Repeat this process until the boiling point rises to about 150°. Read the barometer and enter your results in a tabular form as follows :—

Mass of salt added.	Mass of contents of flask after boiling.	Percentage of solid in solution.	Boiling point.
m_1	M_1	π_1	t_1
m_2	M_2	π_2	t_2
m_3	M_3	π_3	t_3
...	...	...	...

Barometric pressure, ... mm.

The composition of crystallised Calcium Chloride is
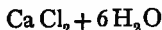
$$Ca\,Cl_2 + 6\,H_2O$$
$$111 + 108 = 219,$$

therefore the mass of solid present is $\frac{111}{219}$ths of the mass of the salt added. To get the numbers in the third column let us find π_3. The mass of salt added is $m_1 + m_2 + m_3$, therefore the mass of solid present is $\frac{111}{219}(m_1 + m_2 + m_3)$. Thus the percentage of Calcium Chloride in the contents of the flask is

$$\frac{111\,(m_1 + m_2 + m_3)}{219 \times M_3} \times 100.$$

Plot a curve, taking the percentages as abscissae and the

corresponding boiling points as the ordinates, marking the origin of temperatures 100°.

N.B. At certain stages of the experiment, it may be well to concentrate the solution by boiling the water away instead of by adding more salt.

Determine as above the variation of the boiling point with solutions of Potassium Nitrate and of Sodium Chloride [8].

B. EXPANSIONS.

The *coefficient of linear expansion* is that length by which 1 cm. of a substance expands on being heated 1°C.

The *coefficient of cubical expansion* is that volume by which 1 cub. cm. of a substance expands on being heated 1°C.

12. Determination of the coefficient of linear expansion of a metal tube [9].
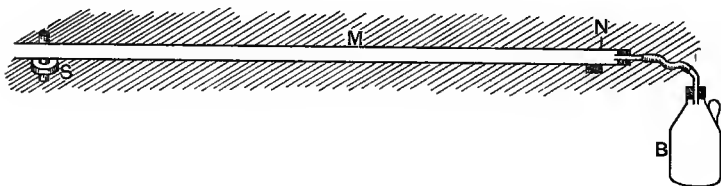
Fig. 5.

[*M* is the metal tube, about 120 cm. in length, firmly fixed at one end by a short piece of metal rod passing through a slot *S* fixed in the wall. Near the other end, which rests on a fixed support, is soldered the needle *N*. Through the cork, closing this end, passes a piece of glass tubing, connected by india-rubber tubing with an elbow-tube, passing tightly through the cork of the boiling can *B* [10].]

Apparatus (Fig. 5). Microscope with a divided scale in the eyepiece : Thermometer: Bunsen Burner.

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[8] In the case of anhydrous salts add about 10 grams each time.

[9] I believe this method is due to my predecessor, Mr. A. D. Hall.

[10] An ordinary oil can, through the cork of which passes an elbow-tube, is a convenient boiling can. Cans made of copper last much longer than the tin ones, as rust eats holes into the bottom of the latter.

Experiment. Measure the distance, *L*, between the fixed end and the needle, and note the temperature, *t*, of the room. Arrange the microscope as as to focus an edge of the needle on one of the extreme scale-divisions in the eyepiece, remembering that the direction of the motion of the needle, when the rod expands, is reversed by the microscope. When once adjusted be careful not to move the apparatus during the experiment. Now boil the water in the can and allow the steam to pass through the tube. The tube will expand, and the needle will be seen to move across the scale. Continue to pass the steam until the needle comes quite to rest. Count the number of scale divisions the needle has moved over and multiply by the known value of a scale division [11] in centimetres. This gives us the length, *l*, by which the tube has expanded. Read the barometric height, and find from the tables [Appendix A. 10] the temperature, *T*, of boiling water at this pressure. Then

L cm. have expanded by l cm. for a rise of temperature $(T-t)^\circ$
$$[\tau^\circ \text{ suppose}]$$

∴ 1 cm. expands by $\dfrac{l}{L\tau}$ cm. for a rise of 1°C,

which is the required coefficient of linear expansion of the tube.

Determine as above the coefficients of linear expansion of Iron, Copper and Brass.

13. Determination of the cubical expansion of glass by the specific gravity bottle.

Apparatus. Specific Gravity bottle : Beaker : Thermometer : Sand-bath : Bunsen Burner : Mercury.

Experiment. Thoroughly clean and dry [12] a specific gravity bottle. Counterpoise it [13] and then fill it with Mercury, being

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[11] This is easily obtained by looking through the microscope at a metre rule and noting how many millimetres are covered by the scale. The scale in use in the writer's laboratory covers 2 mm. and is divided into 100 divisions.

[12] See Appendix B. 4.

[13] Bullets, shot, and sand are convenient to counterpoise bodies with.

careful not to handle it more than absolutely necessary. Find
the mass, M, of the mercury it contains. Place the bottle in a
beaker of water whose temperature, t, must be noted. Heat
the water till it boils. Read the barometer and refer to the
tables [Appendix A. 10] to get the boiling point, T, of the water
under this pressure. Take out the specific gravity bottle care-
fully and dry it. Weigh it again to determine the mass, M', of
mercury remaining in it. The mass of the mercury that has
been expelled is $M–M'$, or m suppose. The mercury, on cool-
ing to $t°$, would contract and leave a space representing the
volume of the expelled mercury. Hence it is evident that
M' grams of mercury at $t°$ would, on being heated to $T°$,
expand by an amount represented by m grams and fill the
bottle. We may take these masses as proportional to the
volumes, hence

M' cub. cm. of mercury expand by m cub. cm. for $(T-t)°$

$$[\tau° \text{ suppose}]$$

$\therefore$ 1 cub. cm. expands by $\dfrac{m}{M'\tau}$ cub. cm. for $1°$C.

This gives us the mean coefficient of expansion of mercury
(Δ) relative to glass between these temperatures. The co-
efficient of expansion of glass (k) may be taken approximately
as the mean real coefficient (δ) less the relative coefficient of
expansion of mercury.

Look in the tables [Appendix A. 2] for the mean real co-
efficient of expansion of mercury between $T°$ and $t°$, and from it
subtract the above value of Δ in order to get the coefficient of
expansion of the glass, and enter your results as follows:—

$$M = \ldots \text{ grs.} \quad \text{Barometric height} \ldots \text{mm.} \quad T = \ldots°$$
$$M' = \ldots \text{ grs.} \qquad\qquad\qquad\qquad\qquad\qquad t = \ldots°$$
$$\therefore \quad m = \ldots \text{ grs.} \quad \text{Tables give } \delta = \ldots \quad \therefore \quad \tau = \ldots°$$

$$\Delta = \frac{m}{M'\tau} = \ldots$$
$$\therefore \quad k = \ldots$$

*14. Determination of the cubical expansion of a solid by Matthiessen's method.

Apparatus. A balance [14] with a hole bored in the base under one of the pans: a small piece of the Solid in the form of a tube or thin sheet [e. g. a piece of glass tube]: Beaker: Thermometer: Bunsen Burner.

Experiment. Hang the solid to one arm of the balance by a very fine wire, passing through the hole in the base of the balance, arranging it so that it can dip into a beaker of water. Counterpoise the solid. Bring up a beaker of water so as to immerse it completely, being careful not to let it touch the sides. Remove any air bubbles from it by a feather, and note the temperature, t, of the water. Restore equilibrium by known weights, ω_1. This represents the weight of an equal volume of water at t°. If V is the volume of the solid and d_t the density of water at t°, we have

$$V d_t = \omega_1. \qquad (1)$$

Now immerse the solid in hot water and allow it to remain for a minute or so until it is of the same temperature as the water [14]. Determine this temperature, T, and quickly restore equilibrium by known weights, ω_2.

If x is the coefficient of expansion of the solid, its volume has now become $V(1 + x\tau)$, where $\tau = (T - t)^\circ$; and, if d_T is the density of water at T°, we have

$$V(1 + x\tau) d_T = \omega_2. \qquad (2)$$

Dividing (1) by (2) we get

$$\frac{d_t}{(1 + x\tau) d_T} = \frac{\omega_1}{\omega_2};$$

$$\therefore \quad x = \frac{\omega_2 d_t - \omega_1 d_T}{\omega_1 \tau d_T}.$$

Referring to the tables (Appendix A. 1) for the densities of water at t° and T° we can find x.

Repeat the experiment twice more, raising the water each

---

[14] It is best, if possible, to have the balance at a sufficient height from the table to allow the beaker to rest on a sand-bath over a burner. By adjusting the flame of the burner we can keep the water at a fairly constant temperature while weighing.

time to a higher temperature. Enter your results in a tabular form and compare your values of x.

Determine as above the coefficients of expansion of Glass, Copper and Zinc.

*15. Determine the cubical expansion of glass by the weight thermometer.

Apparatus. A piece of fairly thick glass tubing about 15 cm. long and 1·5 cm. in diameter : Beaker : Thermometer : Evaporating Dish : Crucible : Retort-stand : Bunsen Burner : Mercury.

Experiment. Clean and dry the glass tube. Hold it in the flame of a Bunsen's burner and heat it near one end, keeping on turning it round so as to heat it uniformly. When quite viscous draw it out while still in the flame and so close the end. Anneal it by holding the closed end in an ordinary gas flame until it is covered by a deposit of carbon and allowing it to cool gradually.

When it is cool, heat it uniformly near the other end, and when viscous take it out of the flame and draw it out
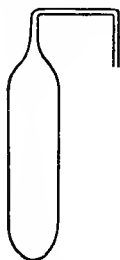
Fig. 6.

to a fine tube. Bend it as in the figure, and cut off with a file any superfluous tube. Counterpoise this weight thermometer. Then support it by a wire so that its beak dips under the surface of clean dry mercury [Appendix B. 5] in an evaporating dish resting on a ring of the retort stand. We have now to fill the thermometer with mercury. This we do by heating it so as to drive out some air, and then allowing it to cool again [15], when the atmospheric pressure will force some mercury in. When, by alternately heating and cooling, we have got it about three parts full, boil the mercury so as to expel all the remaining air, and allow the thermometer to remain with its beak still under the mercury until it has cooled down

---

[15] We must be careful to prevent the glass cracking by the contact of the cold mercury and the heated glass. The sides and not the bottom of the thermometer had better be heated first and the mercury in the dish warmed as well.

nearly to the temperature of the room. Then bring up a beaker of cold water so that as much as possible of the thermometer is immersed, resting the beaker on another ring of the retort-stand. By means of a siphon change the water three times at intervals of five minutes. While this is going on counterpoise the crucible. We have now the thermometer full of mercury at the temperature, t, of the water, which we note. Take away the dish containing the mercury and replace it by the counterpoised crucible, so that it may catch any of the liquid that may be expelled from the thermometer. Now heat the water about 10° above the temperature of the room [16], keeping the water well stirred; note the temperature, t_1, and weigh the mercury expelled, m_1. Replace the crucible and heat again 10° higher: weigh the total quantity of liquid in the crucible, m_2: continue alternately heating and weighing thus till the water boils. Then take out the weight thermometer, dry it carefully, and find the mass, M_n, of the mercury it contains. Enter your results in a tabular form as follows :—

Temperatures.	Mass of mercury in crucible.	Mass of mercury in weight thermometer.	Mean relative expansion of mercury. (Δ)	Mean absolute expansion of mercury. (δ)	Coefficient of expansion of glass. ($\delta - \Delta = k$)
t		M			
t_1	m_1	M_1	Δ_1	δ_1	k_1
t_2	m_2	M_2	Δ_2	δ_2	k_2
...	...	...	..	...	...
t_n	m_n	M_n	Δ_n	δ_n	k_n

Mean =   . . .

The numbers in the third column are obtained thus: the

---

[16] Each time before taking the crucible away we must be sure the mercury is at the same temperature as the water. To ensure this regulate the flame so as to keep the temperature fairly constant for a minute, keeping the water well stirred. Before removing the crucible it is advisable to touch the beak of the weight thermometer with its side to detach any liquid adhering to the beak by capillary attraction.

mercury contained in the weight thermometer at the beginning, M, is equal to $M_n + m_n$,

$$\therefore \quad M = M_n + m_n,$$
$$M_1 = M - m_1,$$
$$M_2 = M - m_2,$$
&c.

To get the numbers in the fourth column let us find Δ_2: M_2 c.c. of mercury evidently expand by $m_2 - m_1$ c.c. for $(t_2 - t_1)^\circ$,

$\therefore$ 1 c.c. expands by $\dfrac{m_2 - m_1}{M_2 (t_2 - t_1)}$ c.c. for 1°, which is Δ_2, the mean coefficient of relative expansion between t_2° and t_1° (see Experiment 13). The numbers in the fifth row are found from the tables (Appendix A. 2). The coefficient of expansion of glass is found by subtracting the corresponding numbers in the fourth and fifth rows. Take the mean of the results, and find the probable error (Appendix B. 1).

N.B. If we assume the coefficient of expansion of glass known, we can by the above experiment determine the absolute coefficient of expansion of mercury.

*16. Determination of the cubical expansion of a solid by the weight thermometer.

Apparatus. A piece of fairly thick glass tubing about 15 cm. long and 1 cm. in diameter: Beaker: Thermometer: Evaporating Dish: Crucible: Retort-stand: Bunsen Burner: Glycerine: Leaden Shot.

Experiment. Close one end of the tubing in the flame, and introduce a known mass, M_1, of shot. Draw the other end out and bend as in Experiment 15. Weigh and determine the mass of the glass vessel. Fill it in the manner described in Experiment 15, using glycerine instead of mercury, being careful to get rid of all air bubbles. After it has attained the temperature, t, of the water in the beaker, replace the evaporating dish by a previously counterpoised crucible. Heat the water to boiling and continue boiling for five minutes, so that the shot may attain the temperature of the water. Note the barometric height, and hence determine the temperature, T, of boiling

water. When no more glycerine is expelled weigh the crucible and determine the mass, m, of the glycerine in it. Then take the weight thermometer out of the water, dry it, and determine the mass, M_2, of the glycerine remaining in it.

On raising the temperature through $(T-t)^{\circ}$, τ° suppose, the lead, glycerine, and glass have expanded, and the volume of the expelled glycerine evidently is equal to the sum of the expanded volumes of the lead and the glycerine less the expanded volume of the glass vessel.

If D_1 is density of Lead and x its coefficient of cubical expansion,

if D_2 is density of Glycerine and a its coefficient of cubical expansion,

and if k is the coefficient of cubical expansion of the glass, then the volume of the Lead taken is

$$\frac{M_1}{D_1} = V_1 \text{ c.c., suppose,}$$

and the volume of the Glycerine that filled the weight thermometer at t° is $\quad \dfrac{M_2 + m}{D_2} = V_2 \text{ c.c., suppose;}$

∴ the volume of the glass vessel at t° is $V_1 + V_2$ c.c., and the volume of the expelled Glycerine is

$$\frac{m}{D_2} = v \text{ c.c., suppose.}$$

Therefore

$$v\,(1 + a\tau) = V_1\,(1 + x\tau) + V_2\,(1 + a\tau) - (V_1 + V_2)\,(1 + k\tau),$$
$$\therefore \quad x = \frac{(V_1 + V_2)\,k\tau + v\,(1 + a\tau) - V_2 a\tau}{V_1 \tau}.$$

All the quantities on the right-hand side being known, we can determine x.

Determine as above the coefficients of expansion of iron and copper, both in the form of filings.

17. Determination of the cubical expansion of a liquid by the bulb-tube.

Apparatus. A long tube of narrow bore with a bulb at one

end. (The tube must be graduated in equal divisions and the volume of the bulb and of a division must be known [Appendix B. 2.]) Beaker: Thermometer: Sand-bath: Bunsen Burner: Turpentine.

Experiment. Fill the bulb and a small portion of the tube with turpentine and support it in a beaker of water resting on a sand-bath. Read the temperature, t, of the water and the total volume, V, occupied by the turpentine. Heat the water, keeping it continually stirred, up to a temperature at which the turpentine nearly fills the tube. Lower the flame and when the temperature has become constant read it, $T°$ suppose, and note the total volume, V', occupied by the turpentine. It is evident that the original volume, V, has expanded by $(V'-V)$, v suppose, for a rise of temperature $(T-t)°$ [$\tau°$ suppose].

$$\therefore \quad V \text{ c.c. expand by } v \text{ c.c. for } \tau°,$$

$$\therefore \quad 1 \text{ c.c. expands by } \frac{v}{V\tau} \text{ c.c. for } 1°,$$

which is the mean coefficient of relative expansion of turpentine between the two temperatures.

To get the mean coefficient of absolute expansion add to this the coefficient of cubical expansion of glass.

Determine as above the coefficients of expansion of glycerine and alcohol.

18. Determination of the cubical expansion of water at different temperatures by the bulb-tube.

Apparatus. A bulb-tube similar to the one used in Experiment 17, containing water instead of turpentine: Beaker: Thermometer: Sand-bath: Bunsen Burner: Curve-paper.

Experiment. Support the bulb-tube in a beaker of water on a sand-bath. Read the temperature, t, of the water and the total volume, V, occupied by that in the tube. Heat the water gradually, keeping it well stirred, and at about every five degrees rise in temperature read off the total volumes occupied by the water in the tube as well as the corresponding temperatures [17].

[17] To ensure that the liquid is at the temperature indicated, when it has been heated nearly to the temperature required, lower the flame so as to

Continue this until the water nearly fills the whole of the tube : enter your results in a tabular form as follows :—

Temperatures.	Total volumes occupied by the water.	Relative expansion of 1 c.c.
t	V	1
t_1	V_1	β_1
t_2	V_2	β_2
...	...	...

To get the numbers in the third column divide those in the second column by V, which will give us the volumes at the different temperatures which 1 c.c. at $t°$ would occupy.

Plot your results on a curve taking the temperatures as abscissae and the numbers in the third column as ordinates. What does the form of the curve show you?

19. Determination of the cubical expansion of a liquid by the weight thermometer.

Apparatus. Weight thermometer as in Experiment 15: Beaker: Thermometer: Evaporating Dish: Crucible: Retort-stand: Bunsen Burner: Glycerine.

Experiment. After counterpoising the weight thermometer fill it with glycerine according to the instructions of Experiment 15. When the glycerine is at the temperature, t, of the water replace the evaporating dish by a previously counterpoised crucible. Heat the water, stirring continually, until it boils. Note the barometric height and determine the boiling point, T. Remove the crucible [18] and find the mass of glycerine, m, that it contains. Take out the weight thermometer, dry it, and find the mass, M, of glycerine remaining in it. This glycerine would, on being cooled to $t°$, contract, and would leave a space representing the volume of the expelled glycerine.

keep the temperature fairly constant for a minute. Now take the reading of the thermometer and the volume of the liquid.

[18] See Note 16.

Hence M grams of glycerine at $t°$, on being heated to $T°$, would expand by an amount represented by m grams and would fill the weight thermometer. Taking, as we may, these masses as proportional to the volumes,

M c.c. of glycerine expand by m c.c. for $(T-t)°$, $[τ°$ suppose$]$;

$$\therefore \quad \text{1 c.c. expands by } \frac{m}{Mτ} \text{ c.c. for 1}°,$$

which gives us the mean coefficient of relative expansion between these temperatures. To get the mean absolute expansion add the coefficient of cubical expansion of glass.

Determine as above the coefficient of expansion of turpentine.

*20. Determination of the cubical expansion of mercury at different temperatures by the specific gravity bottle.

Apparatus. Specific gravity bottle : Beaker : Thermometer : Sand-bath : Bunsen Burner : Mercury : Curve-paper.

Experiment. Thoroughly clean and dry the specific gravity bottle. Counterpoise it and then fill it with clean dry mercury [Appendix B. 4, 5], and find the mass, M, of the liquid. Place the bottle in a beaker of water, whose temperature, t, we note. Heat the water, stirring continually, until the temperature has risen about 10°. When the mercury is at the temperature of the water [19], read the thermometer, t, take the bottle out, dry it, and find the mass, M_1, of the mercury in it. Repeat this series of observations for about every 10° rise in temperature until the water boils. Read the barometer and find the boiling point, T, and enter your results in a tabular form as follows:—

Tempera-tures.	Mass of mercury in bottle.	Mean coefficients of relative expansion.	Mean coefficients of absolute expansion.	Expansion of 1 c.c.
t	M			1
t_1	M_1	Δ_1	δ_1	β_1
t_2	M_2	Δ_2	δ_2	β_2
...	...	...	...	...

[19] See Note 17.

In order to get the numbers in the third column let us find Δ_2. M_2 c.c. expand by $M_1 - M_2$ c.c. for a rise in temperature $(t_2 - t_1)^\circ$,

$\therefore$ 1 c.c. expands by $\dfrac{M_1 - M_2}{M_2(t_2 - t_1)}$ c.c. for 1°, which is Δ_2, the mean coefficient of relative expansion of mercury between these temperatures. The numbers in the fourth column are obtained by adding the coefficient of cubical expansion of glass to those in the third column.

The numbers in the fifth column are found by dividing into M the series of numbers in the second column: e.g.

$$M_2 \text{ at } t^\circ \text{ expand to } M \text{ at } t_2^\circ\,;$$

$$\therefore \quad 1 \text{ c.c. at } t^\circ \text{ expands to } \frac{M}{M_2} \text{ [i.e. } \beta_2] \text{ at } t_2^\circ.$$

Plot a curve of your results, taking the temperatures as abscissae and the numbers in the fifth column as ordinates, and compare this curve with the similar one for water obtained in Experiment 18.

*21. Determination of the cubical expansion of a liquid by Matthiessen's method.

Apparatus. The balance used in Experiment 14: A piece of glass tubing about 4 cm. long: Beaker: Thermometer: Bunsen Burner: Glycerine.

Experiment. Proceed in a similar manner to that described in Experiment 14, and find the loss of weight of the glass tube when immersed in glycerine at different temperatures. If V is the volume of the glass tube and d_t the density of glycerine at t°, and ω_1 the loss of weight,

$$V d_t = \omega. \qquad (1)$$

On heating the glycerine to T°, if k is the known coefficient of expansion of the glass, d_T the density of glycerine at T°, and ω_2 the loss of weight of the glass in this case,

$$V(1 + k\tau)\,d_T = \omega_2. \qquad (2)$$

Dividing (1) by (2) we have

$$\frac{d_t}{(1 + k\tau)\,d_T} = \frac{\omega_1}{\omega_2}.$$

If x is the mean absolute coefficient of expansion of glycerine

$$d_t = d_T(1 + x\tau);$$

$$\therefore \quad \frac{1 + x\tau}{1 + k\tau} = \frac{\omega_1}{\omega_2};$$

$$\therefore \quad x = \frac{\omega_1(1 + k\tau) - \omega_2}{\omega_2\tau}.$$

Repeat the above twice more, raising the glycerine each time to a higher temperature. Enter your results in a tabular form and compare your values of x.

Determine as above the coefficients of expansion of Turpentine and Amyl Alcohol.

22. Determination of the cubical expansion of a liquid by Dulong and Petit's method.
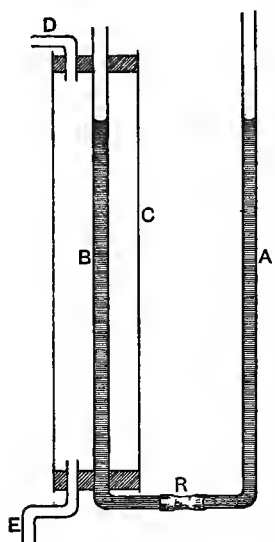
Fig. 7.

[A and B are two glass tubes, about .75 cm. in internal diameter and 80 cm. in length, bent at right angles at the bottom where they are joined tightly together by a piece of india-rubber tubing R. B passes through two corks, closing the ends of a wide glass tube C about 3 cm. in diameter, and nearly but not quite as long as B. Through these corks also pass two elbow tubes D and E—the upper one is connected with a boiling can (see note 10) and the lower one is to allow the escape of the steam. This apparatus should be fixed by pieces of leather to a wooden support.]

Apparatus (Fig. 7). Thermometer: Boiling can: Bunsen Burner: Amyl Alcohol.

Experiment. By a piece of india-rubber tubing fit the elbow tube D to the boiling can. Hang a thermometer, by the tube A. Pour in amyl alcohol coloured by a little carmine so that it stands about 60 cm. above the horizontal tube. Arrange the lower tube so that it is quite horizontal. Pass steam through the jacket C, placing

a vessel under E to catch the condensed steam. Pass the steam for some time until the liquid in B has finished expanding. Read the height, H, of the liquid in B and the height, h, of that in A above the top of the horizontal tube. Read the temperature, t, by the thermometer hanging near A. Note the barometric height and determine the boiling point T.

Now the height H at $T°$ balances the height h at $t°$, so that, if the height h were heated to $T°$, its length would become H. Therefore, if x is the mean absolute coefficient of expansion of the liquid,

$$h\,(1+x\tau) = H, \text{ where } \tau° = (T-t)°,$$
$$\therefore \quad x = \frac{H-h}{h\tau}.$$

Determine as above the coefficients of expansion of turpentine and glycerine.

23. Determination of the change of volume on melting.

Apparatus. A piece of glass tubing about 25 cm. long: Beaker: Thermometer: Bunsen Burner: Mercury: Wax.

Experiment. Draw out one end of the glass tube to a point, and calibrate about 6 cm. of it from the other end [Appendix B. 3]. Counterpoise it and introduce through the pointed end a column of about 6 or 7 cm. of melted wax. Allow this to solidify and fuse the end with a blowpipe. If there is any air remaining melt the wax again and drive the air out by heat. Find the mass, M, of the wax introduced and look in the tables for its density, D: then its volume is $\frac{M}{D}$ (or V) cub. cm. Now pour into the tube some clean mercury until its level is about 5 cm. from the top. Immerse the tube in a beaker of water on a sand-bath so that all the wax is under the surface and support a thermometer near it. Heat the water, keeping it well stirred, up to the known melting point of wax. Directly it begins to melt read the level, h_1, of the mercury. Lower the flame and continue heating and stirring till the wax has all just melted. Read the level, h_1', of the mercury again. This change of level represents a known change of volume v_1. Take away

the burner and allow the wax to solidify. When it has just all solidified read the level of the mercury. Repeat this twice more: enter your results in a tabular form and take the mean change of volume as the correct result.

Level of mercury when wax has		
melted.	solidified.	Change of volume.
h_1'	h_1	v_1
h_2'	h_2	v_2
h_3'	h_3	v_3
	Average	. . . c.c.

Original volume, $V = \ldots$ c.c.
Percentage change of volume on melting $= \ldots \%$.

Find the probable error of the results (Appendix B. 1).

Determine as above the change of volume of Stearic Acid and of Ice on melting.

24. Determination of the temperature of the maximum density of Water.
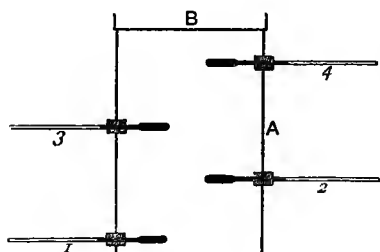
Fig. 8.

[A cylindrical tin vessel A (a biscuit tin will do), about 10 cm. in height and 6 cm. in diameter, has four smooth holes bored at equal distances from each other, to which corks are fitted water-tight. Through each cork passes a thermometer. The cover B of the vessel is turned over and rests on the top, serving to contain the freezing mixture.]

Apparatus (Fig. 8).
Ice : Salt : Curve-paper.

Experiment. Fill the vessel A quite full with distilled water and place as much of a freezing mixture of crushed ice and salt

[1 part of salt to 2 parts of ice] as possible into the cover *B*. Replace the cover so that the bottom of it is in contact with the surface of the water in *A*. Mark the temperatures indicated by the four thermometers every minute and arrange your results in a tabular form. No 1 will cool rapidly at first since the water on cooling becomes denser and sinks to the bottom. No. 2 will cool more slowly, and No. 3 and 4 still more slowly until the lowest thermometer reaches the temperature of maximum density of water (about 4°). This one remains stationary while No. 2, 3, and 4 will in order arrive at this temperature. After this the water on further cooling expands, and being less dense No. 4, which was the last to reach 4°, will be the first to cool to 0°. The other thermometers, No. 3, 2, 1, will successively attain 0°. Plot on the same piece of curve-paper your results for the four thermometers, taking the times as abscissae and the corresponding temperatures for the ordinates. It will be found that the curves will cross each other along a horizontal line, which, on being continued, cuts the temperature axis at the temperature of the maximum density of water. It is important that the observer should not come closer to the apparatus than is absolutely necessary to read the thermometers as the radiation from the body will prevent the water cooling sufficiently.

25. Determination of the expansion of air at constant pressure (Method 1) [20].

Apparatus. A piece of thermometer tubing about 15 cm. long: Beaker: Thermometer: Sand-bath: Bunsen Burner: Mercury: Curve-paper.

Experiment. Dry the thermometer tubing thoroughly: close one end of it in the flame. Dip the open end under the surface of clean mercury and heat it strongly with the Bunsen to drive out a portion of the air. On allowing it to cool, a thread of mercury will be forced up the tube, enclosing a certain volume

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[20] In this and the two following experiments we neglect the expansion of the glass.

of air.   Tie this tube to a thermometer, placing the closed end opposite the zero.   Support them vertically in a beaker of water on a sand-bath so that the whole column of air is under the surface.   Read the temperature, t, of the water and the volume, v, of the enclosed air in terms of the thermometer divisions. Heat the water gradually, keeping it well stirred.   At about every $10°$ rise of temperature read the thermometer and the volume of the enclosed air [21].   Continue this until the water boils and enter your results in a tabular form.

Temperature.	Volume of air.	Mean coefficient of expansion of air.	Expansion of 1 c.c.
t	v		1
t_1	v_1	a_1	β_1
t_2	v_2	a_2	β_2
...	...	...	...

To get the numbers in the third column let us find a_2.

A volume v_1 c.c. expands by $v_2'-v_1$ c.c. for a rise of temperature $(t_2-t_1)°$;

$\therefore$ 1 c.c. expands by $\dfrac{v_2-v_1}{v_1\,(t_2-t_2)}$ c.c. for $1°C$, which gives us a_2,

the mean coefficient of expansion of air between these temperatures.   To get the numbers in the fourth column divide those in the second column by v.

Plot your results on a curve, taking the temperatures as the abscissae and the corresponding numbers in the fourth column as the ordinates.   What does the form of the curve show? Compare it with the curve obtained in Experiment 18.

26. Determination of the expansion of air at constant pressure (Method 2).

Apparatus.   A round bottomed flask fitted air tight with a one-holed bung.   Through the hole passes a piece of glass

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[21] See Note 17.

tubing to which is attached a short piece of india-rubber tubing. A vessel [in which to place the flask] containing a little water : Beaker : Thermometer : Litre measuring jar : Clip : Bunsen Burner.

Experiment. Thoroughly dry the flask, and after fitting the bung tightly into the neck support it inside the vessel so that it is just above the surface of the water. Cover with a piece of cardboard through a hole in which the neck of the flask passes. Boil the water briskly for about 5 or 10 minutes, and, after reading the barometer, find the temperature, T, of boiling water. We now have the flask full of air at $T°$. Clip the india-rubber tubing and take the flask out of the vessel and let it cool. Then invert it so that its neck dips under cold water, and open the clip. The water will rise in consequence of the contraction of the air. Shake the water up with the air for at least five minutes, keeping the neck of the flask under water. Then clip the india-rubber tubing and measure the volume, v, of the water that has entered and note its temperature, t. Then fill the flask with water up to the point where the india-rubber tubing was clipped in the first instance and measure its total volume, V.

It is evident that a volume $V-v$ c.c. of air would on expanding by v c.c. fill the flask at $T°$.

∴ $V-v$ c.c. expand by v c.c. for a rise of temperature
$$(T-t)° \ [\tau° \text{ suppose}],$$

∴   1 c.c. expands by $\dfrac{v}{(V-v)\,\tau}$ c.c. for 1°C,

which is the mean coefficient of expansion of air between these temperatures.

27. Determination of the coefficient of increase of pressure of air at constant volume.

[A glass tube with a bulb B about 5 cm. in diameter, blown at one end, is bent twice at right angles as in the figure, the longer limb being from 40 to 45 cm. in length. All moisture must be carefully expelled from it by warming the bulb over a flame. The end of the tube is joined by a piece of india-rubber tubing [22] about 50 cm. long to another similar piece

[22] Thick india-rubber tubing lined with canvas ought to be used to withstand the pressure.

of glass tubing A about a metre in length. Fill the longer limb of B, the india-rubber tubing and part of the tube A with clean dry mercury. A
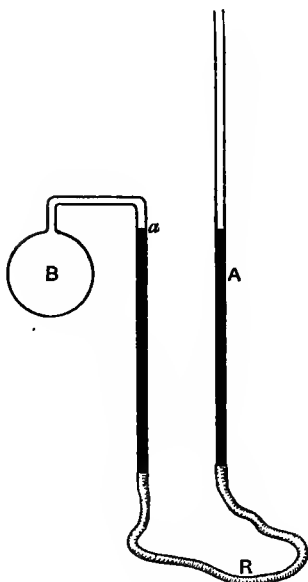
Fig. 9.

small piece of paper is gummed on at 'a' to serve as a mark. This apparatus should be attached by pieces of leather to a wooden support. Instead of using the india-rubber tubing a more convenient method is to join the ends of the two tubes by two branches of a thick india-rubber T-tube, the third branch being firmly bound to the nozzle of an ordinary india-rubber air ball. Pressure is exerted on the mercury filling the ball by a screw passing through a piece of wood resting on the ball, the opposite edge of the piece of wood being hinged to the base-board.

Apparatus (Fig. 9). Beaker: Thermometer: Metre rule: Bunsen Burner: Curve-paper.

Experiment. Bring a beaker of water up so as to completely immerse the bulk B and as much of the tube as possible. Raise or lower A[23] so as to bring the level of the mercury exactly to the mark a. Note the temperature, t, of the water and the difference of level, h, if any, of the mercury in the two tubes. Read the barometric height, H. The enclosed air is now at temperature t and under a pressure $H \pm h$, according as the mercury in A is higher or lower than that in the other limb. Heat the water in the beaker, keeping it continually stirred, till the temperature rises about 10°. The air will expand and press down the mercury below a. In order to reduce the air to the same volume as before, raise the tube A[23] until the level of the mercury returns to a. Note the temperature, t_1, and the differ-

[23] Or if the india-rubber ball replaces the tubing alter the levels by the screw.

ence, h_1, of the heights of the mercury columns, being sure that the air and the water are at the same temperature [24]. Take similar readings at about every 10° rise in temperature until the water boils, and enter your results in a tabular form as follows:—

Temperatures.	Difference in heights of mercury columns.	Pressure of enclosed air.	Mean coefficient of increase of pressure.
t	h	$H \pm h = P$	
t_1	h_1	$H + h_1 = P_1$	a_1
t_2	h_2	$H + h_2 = P_2$	a_2
...	...	...	...

Barometric height, $H = ...$ mm.

To get the numbers in the fourth column, let us find a_2.

The pressure P_1 increases to P_2 for a rise of temperature $t_2 - t_1$,

∴ unit pressure increases by

$$\frac{P_2 - P_1}{P_1 (t_2 - t_1)} = \frac{h_2 - h_1}{P_1 (t_2 - t_1)} \text{ for a rise of } 1°,$$

which is the mean coefficient of increase of pressure between these temperatures.

Plot your results in a curve taking the temperatures as abscissae and the corresponding pressures in the third column as ordinates, and compare with the curve in Experiment 25.

We have assumed that the small volume of air in the short branch tube between the level of the water in the beaker and the mark a is at the same temperature as the air in bulb. For greater accuracy we should have to allow for this not being so.

N. B. When you have finished be careful to lower A as far as it will go, as otherwise, when the air cools, mercury will be forced into the bulb.

[24] See Note 17.

C. CALORIMETRY.

The unit of heat, called a *calorie*, is that quantity of heat which is required to raise 1 gram of water one degree centigrade. We shall assume that this is constant all through the scale of temperatures.

The *specific heat* of a substance is the quantity of heat required to raise 1 gram of the substance 1°C, or the quantity emitted by 1 gram when cooling 1°C.

The heat of fusion is the quantity of heat required to transform 1 gram of a solid to the liquid state at the melting point or *vice versâ*. *The heat of vaporisation* is the quantity of heat required to transform 1 gram of a liquid to vapour at the boiling point or *vice versâ* under given atmospheric pressure.

N. B. In the following experiments on the measurements of quantities of heat, we must arrange to lessen as much as possible conduction and radiation of heat from the calorimeter. To prevent conduction the calorimeter may either be supported on a triangle of cord tied to a ring of the retort-stand, or may be packed in an empty beaker with cotton wool, or better still, be supported by strings inside a tin vessel.

The methods by which the errors due to radiation are corrected are beyond the scope of this book, and therefore we must try and lessen the amount of radiation. This may be done by polishing the outside of the calorimeter and the inside of the tin vessel in which it is placed, and also by placing so much liquid in the calorimeter that the final temperature may not be much above the temperature of the room. We shall assume that the above precautions are taken in each of the following experiments in Calorimetry. When two thermometers are used they must always be compared first, either as in Experiment 3 or by dipping them into the same beaker of water, and the reading taken on one must be reduced to what it would be on the other.

28. Determination of the water value of the Calorimeter and Thermometer.

Apparatus. A metal vessel to be used as a Calorimeter: Beaker: Two Thermometers: Sand-bath: Bunsen Burner.

Experiment. Counterpoise the calorimeter, and support a thermometer with its bulb inside the vessel. Heat some water in a beaker to about $25°$ or $30°C$, and take its temperature, T, with the other thermometer. Let the temperature of the calorimeter be $t°$. Quickly pour some of the warm water into the calorimeter so that it is about half full. Stir well and read the highest temperature, θ, to which the thermometer rises before it begins to cool again. Weigh and find the mass, m, of water that has been poured in.

m grams of water have cooled from $T°$ to $\theta°$, therefore they have given out $m(T-\theta)$ calories. These have been absorbed by the calorimeter and thermometer, raising their temperature from $t°$ to $\theta°$, $\therefore \dfrac{m(T-\theta)}{\theta-t}$ calories would raise them $1°C$. This quantity is called their '*water value*' or '*heat capacity*.' It is evidently equal to the number of grams of water that would have been raised the same number of degrees.

Repeat this experiment, using water that has been heated to $70°$, and enter your results in a tabular form [25].

29. Determination of the specific heat of a solid by the method of mixtures (Method 1).

Apparatus. Calorimeter [26]: Two Thermometers: Beaker: Test-tube: Bunsen Burner: Leaden Shot.

Experiment. Fill the test-tube half full of shot and put the bulb of the thermometer in the middle of it. Put the test-tube in a beaker of water and heat to boiling. Counterpoise the calorimeter, fill it two-thirds full of water, and find the mass, m, of water it contains. Note its temperature, t. When the thermometer in the test tube has become quite stationary read the

[25] In determining specific heats and heats of fusion the first value of the water value is to be used: for the heats of vaporisation the second value.

[26] In the following experiments the water value of the calorimeter and thermometer is denoted by μ. See Note 25.

temperature, T, of the shot. Take out the thermometer and quickly transfer the shot to the calorimeter. Stir continually, and
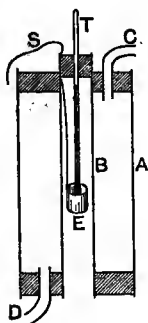
Fig. 10.

note the highest temperature, θ, indicated by the thermometer before it begins to cool. Weigh the calorimeter and determine the mass, M, of shot introduced.

The heat received by the calorimeter and water on being heated from t° to θ° is $(m + \mu)(\theta - t)$, which is equal to the heat given out by the mass M of Lead on cooling from T° to θ°,

$\therefore$ mass M of Lead on cooling $(T - \theta)^\circ$ gives out $(m + \mu)(\theta - t)$ calories ;

$\therefore$ 1 gram of Lead on cooling 1° gives out $\dfrac{(m + \mu)(\theta - t)}{M(T - \theta)}$, which is the required specific heat.

In the case of solids acted on by water we must put in the calorimeter a liquid (whose specific heat, s, we know) that does not act on the solid. The specific heat of the solid is in this case

$$\frac{(m\,s + \mu)(\theta - t)}{M(T - \theta)}.$$

Determine as above the specific heats[27] of Copper, Iron, Zinc, Crystallised Copper Sulphate [in a concentrated solution of the same whose specific heat must be determined as in Experiment 34].

[Instead of heating the solid in a test-tube in a beaker of water, a better plan would be to use the apparatus of Fig. 10. B is a glass tube 9 cm. long and 1.5 cm. in diameter, closed at one end by a cork, through which passes a thermometer T. This tube passes through two corks closing the ends of a wider glass tube A, 10 cm. long and 4 cm. in diameter. Two elbow-tubes pass through the corks of A, the upper one C being connected with a boiling can, the lower one D allowing the steam to escape. The solid is hung by a thread close to the bulb of the thermometer. Steam is passed through the outer cylinder till the thermometer rises no more. By raising the cork we allow the solid to drop into the calorimeter placed under the tube B.]

[27] The solid must either be in small pieces, in powder, or in sheet.

30. Determination of the specific heat of a solid by the method of mixtures (Method 2).

Apparatus. Calorimeter: Beaker: Two Thermometers: Wire cage: Bunsen Burner: Beeswax.

Experiment. In the case of a solid lighter than water, or of one that sticks to the test-tube on being heated, we must first find its mass, M; then place it in a small open wire cage whose mass, m', and specific heat, s, we know, and hang it by a thread in water which we raise to a temperature, T, below the known melting point of the solid. Counterpoise the calorimeter and fill it two-thirds full of water. Find the mass, m, of water introduced and determine its temperature, t. Quickly transfer the cage to the calorimeter, note the final temperature, θ, and weigh again to determine the mass, m'', of water that was carried over. Then since the heat given out by the solid, the cage, and water, m'', is equal to the heat received by calorimeter, thermometer and water, m, we have, if x is specific heat of the solid,

$$[Mx + m's + m''] \, (T-\theta) = (m+\mu) \, (\theta-t) \, ;$$

hence we determine x.

Determine as above the specific heat of Paraffin-wax.

31. Determination of the specific heat of a solid by fusion of ice.

Apparatus. Beaker: Test-tube: Thermometer: Bunsen Burner: Cotton wool: Small block of Ice: Small piece of Lead.

Experiment. Weigh the piece of lead, M, and put it and a thermometer in a test-tube immersed in a beaker of water. Heat the water to boiling. Counterpoise a small piece of cotton wool attached to a piece of glass tube as a handle. Bore out a hole in the block of ice and carefully dry it. When the thermometer in the test-tube has become quite stationary read the temperature, T, and quickly transfer the lead to the hole in the ice. Let it remain till it has cooled to $0°$. Then sop up with the cotton wool the water that is formed. Weigh the cotton wool and determine the mass, m, of the ice that has melted. One gram of ice requires 79.25 calories to melt it,

therefore 79·25 *m* calories have been given out by *M* grams of
lead in cooling from *T*° to o°, therefore 1 gram of lead would
give out $\dfrac{79\cdot25\,m}{MT}$ calories on cooling 1°, which is the required
specific heat.

Determine as above the specific heats of Copper and Iron,
and compare your results with those obtained in Experiment 29.

32. Determination of the specific heat of a liquid by the method of mixtures (Method 1).

Apparatus. Calorimeter: Beaker: Thermometer: Bunsen
Burner: Turpentine.

Experiment. Counterpoise the calorimeter and pour in
enough turpentine to fill it rather more than half full. Find the
mass, *M*, of the turpentine. Boil some water in a beaker [28] and
find from the tables the boiling point, *T*, under the existing
atmospheric pressure. Place a thermometer in the calorimeter
and note the temperature, *t*, of the turpentine. Quickly pour
some of the boiling water into the calorimeter and, stirring the
mixture together, note the highest temperature, *θ*, to which
the thermometer rises. Weight the calorimeter and determine the
mass of water, *m*, introduced.

Now *m* grams of water have cooled from *T*° to *θ*°, and have
given out *m* (*T*−*θ*) calories, which have heated the calorimeter
and the turpentine from *t*° to *θ*°. The calorimeter has taken
μ (*θ*−*t*) calories.

∴ *m* (*T*−*θ*)−*μ* (*θ*−*t*) calories have heated *M* grams of
Turpentine (*θ*−*t*)° ;

∴ $\dfrac{m\,(T-\theta)-\mu\,(\theta-t)}{M\,(\theta-t)}$ calories would raise 1 gram of

Turpentine 1°, which is the required specific heat.

Determine as above the specific heat of Mercury, and of a 15
per cent. solution of Ammonium Chloride, and a 20 per cent. of
solution of Sodium Chloride.

---

[28] The beaker ought to be nearly full of water, so that but little heat is
lost on pouring it into the calorimeter.

33. Determination of the specific heat of a liquid by the method of mixtures (Method 2).

Apparatus. Same as for Experiment 32, and, in addition, Alcohol.

Experiment. In the case of a liquid which emits or absorbs heat on being mixed with water we cannot determine its specific heat as above, but instead of water must use some liquid, whose specific heat, s, is known, which has no action on the given liquid. For instance, to find the specific heat of alcohol, we may raise it to its known boiling point T, and pour it into a mass, m, of turpentine in the calorimeter at temperature, t. As above we determine the final temperature, θ, and mass of alcohol, M, introduced. The heat given out by the alcohol on cooling from T° to θ° is equal to the heat absorbed by the calorimeter and turpentine on being heated from t° to θ°. Therefore,

$$M x (T-\theta) = (ms + \mu)(\theta - t),$$

whence x, the required specific heat of alcohol, can be determined.

Determine as above the specific heat of concentrated sulphuric acid.

34. Determination of the specific heat of a liquid by the method of mixtures (Method 3).

Apparatus. Calorimeter: Beaker: Two Thermometers: Bunsen Burner: Turpentine: Leaden Shot.

Experiment. Instead of using a second liquid as in Experiments 32 and 33 we may use a solid, such as Lead, whose specific heat, s, is known. Having as in Experiment 32 poured into the calorimeter a known mass, M, of Turpentine whose temperature, t, we determine, put some of the shot into a test-tube with a thermometer and place it in a beaker of water which we heat to boiling. When the thermometer stops rising read the temperature, T, of the lead and quickly transfer it to the calorimeter and, stirring, note the final temperature, θ. Weigh the calorimeter and find the mass, m, of shot introduced. The lead on cooling from T° to θ° gives out $ms (T-\theta)$ calories of which $\mu (\theta - t)$ have gone to heat the calorimeter, therefore

$ms(T-\theta)-\mu(\theta-t)$ have heated M grams of Turpentine from $t°$ to $\theta°$;

therefore
$$\frac{ms(T-\theta)-\mu(\theta-t)}{M(\theta-t)}$$

calories would heat 1 gram of Turpentine 1°, which is the required specific heat.

Determine as above the specific heats of Glycerine, of Alcohol, and of concentrated Sulphuric Acid.

35. Determination of the specific heat of a liquid by the method of cooling [29].

Apparatus. Calorimeter [30] : Beaker : Thermometer : Bunsen Burner : Mercury.

Experiment. Counterpoise the calorimeter. Heat some clean dry mercury up to about 70° or 80°, and pour some of it into the calorimeter so as to fill it about half full. Put the thermometer in the mercury [31] and observe the time it takes to cool every 5° down to 40°. Weigh calorimeter and find mass, M, of mercury in it. Empty the mercury out and repeat exactly the same series of observations with water instead ; being careful to fill the calorimeter with the water to the same height as the mercury was at. Let m be the mass of water introduced.

To determine the specific heat from our observations we must remember that Dulong and Petit proved by experiment that when two different liquids are allowed to cool in an enclosure of a constant temperature, the velocity with which either cools only depends on the excess of its temperature over that of the enclosure and on the nature and extent of the surface at which the cooling takes place, and is independent of the nature of the liquid. Therefore, since we fill the same calorimeter to the same height in both cases, the amount of heat given out per minute by the mercury and the water must be the same between the same range of temperatures. If M is the mass of

[29] This method gives satisfactory results only with liquids which are good conductors of heat.

[30] When mercury is used the calorimeter must not be of tin. In this case a glass beaker may do. We must determine its water value as before.

[31] See Note 6.

mercury and if it takes n_1 minutes to cool $5°$, the heat given out per minute is

$$\frac{5\,(Mx+\mu)}{n_1},$$ where x is the specific heat of mercury.

The heat lost per minute by a mass m of water which takes n_1' minutes to cool through the same $5°$ is

$$\frac{5\,(m+\mu)}{n_1'}.$$

Equating the above two expressions we determine x, the required specific heat.

Enter your results in a tabular form as follows :—

Temperature.	Time of cooling.		Specific heat of mercury.
	Mercury.	Water.	
$70°-65°$	n_1	n_1'	x_1
$65°-60°$	n_2	n_2'	x_2
...	...	...	...

Mean = ...

Mass of water, $m = ...$ grs.
Mass of mercury, $M = ...$ grs.

Determine as above the specific heat of Glycerine.

36. Determination of the amount of heat absorbed or emitted on forming a solution.

Apparatus. Calorimeter: Beaker: Thermometer: Powdered Ammonium Chloride.

Experiment. Counterpoise the calorimeter and pour into it 100 grams of water whose temperature, t, we note. Weigh about 15 grams of Ammonium Chloride and transfer it to the calorimeter. Keep stirring the mixture and read the lowest temperature, θ, to which the thermometer sinks. Then weigh the calorimeter and determine the exact mass, m, of the salt introduced.

The amount of heat absorbed cooled the solution, whose known specific heat is s, and the calorimeter from $t°$ to $\theta°$,

therefore the heat absorbed by dissolving 1 gram of Ammonium Chloride in 100 grams of water is

$$Q = \frac{\left[(100 + m)\, s + \mu\right](t - \theta)}{m},$$

which is called the 'Heat of Solution' of the solid.

Determine as above the heat of solution of Sodium Chloride.

N.B. Specific heat of a 15 per cent. solution of Ammonium Chloride is ·89.

Specific heat of a 20 per cent. solution of Sodium Chloride is ·86.

In both cases the alteration per cent. of the specific heat may be taken as ·005.

37. Determination of the Heat of Fusion of Ice.

Apparatus. Calorimeter: Beaker: Thermometer: Ice.

Experiment. Counterpoise the calorimeter and fill it three parts full of water whose mass, m, we determine. Support a thermometer in it and note its temperature, t. Clean a piece of ice and break it up into small pieces and transfer them one by one to the calorimeter, after brushing off the moisture from them, by a pair of crucible tongs whose points are wrapped in flannel. Be careful not to put so much ice in that it cannot all be melted. For 50 grams of water at 15°, 4 cub. cm. of ice will be sufficient. Keep stirring the ice with the water until it is all melted, and note the lowest temperature, θ, to which the thermometer sinks. Weigh the calorimeter and determine the mass, M, of ice introduced. The water and calorimeter have been cooled from t to θ; the amount of heat given out by them is therefore

$$(m + \mu)\,(t - \theta).$$

Part of this has gone to melt the ice and part to raise the resulting water from o to θ. The latter quantity is $M\theta$, therefore the amount gone to melt the ice is

$$(m + \mu)\,(t - \theta) - M\theta,$$

therefore 1 gram of ice requires $\dfrac{(m + \mu)\,(t - \theta) - M\theta}{M}$ to melt to 1 gram of water at o°, which is the required heat of fusion.

38. Determination of the heat of Fusion of a solid (Method 1). ·

Apparatus.   Calorimeter : Beaker : Two Thermometers : Bunsen Burner : Paraffin-wax.

Experiment.   Counterpoise the calorimeter.   Place in it about 5 grams of paraffin-wax whose specific heat, s, is known, and find its mass, M: heat some water in a beaker up to about 70°.   Place a thermometer in the calorimeter and determine its temperature, t.   Read the temperature [32] of the hot water, T, and pour enough of it into the calorimeter to fill it two-thirds full ; keeping it stirred, read the temperature, θ, to which the thermometer sinks before it begins to cool slowly by radiation.   Now weigh the calorimeter and find the mass, m, of water that has been poured in.   The hot water has given out $m(T-\theta)$ calories, of which $(Ms+\mu)$ $(\theta-t)$ have been absorbed by calorimeter and wax in being heated from $t°$ to $\theta°$.

∴ $m(T-\theta)-(Ms+\mu)(\theta-t)$ have been used to melt the wax, therefore 1 gram of wax requires $\dfrac{m(T-\theta)-(Ms+\mu)(\theta-t)}{M}$ to melt it, which is the required heat of fusion.

N.B.—In this experiment we assume that the specific heat of wax in the solid and the liquid state is the same.   This assumption is not a legitimate one, and in the following experiment the error thus introduced is eliminated.

*39. Determination of the heat of Fusion of a solid (Method 2).

Apparatus.   Same as in Experiment 38.

Experiment.   If the specific heat of the substance in the liquid state is not known, we can, by performing two experiments similar to Experiment 38, in which the masses of the wax and the water, as well as the original temperature of the water are different, determine not only the latent heat but also the specific heat of the substance in the liquid state.

[32] The temperature must be such that the final temperature θ is above the melting point of the solid.

Suppose ϕ is the melting point of the solid,

　　　　　s the specific heat of the substance in the solid state,

　　　　　s' the specific heat of the substance in the liquid state,

　　　　　and x the heat of fusion of the solid.

If in the first experiment we take m grams of water at $T°$ and M grams of the solid at $t°$, and find the resulting temperature θ, then since the heat given out by the water is equal to the heat which raises the calorimeter and solid from $t°$ to the melting point, and melts the solid at this temperature and then raises the liquid and the calorimeter to $\theta°$, we have

$$(Ms+\mu)(\phi-t)+Mx+(Ms'+\mu)(\theta-\phi)=m(T-\theta). \quad (1)$$

By taking in a second experiment M' grams of the solid and m' grams of hot water at $T'°$, supposing $\theta'°$ to be the resulting temperature, we have

$$(M's+\mu)(\phi-t)+M'x+(M's'+\mu)(\theta'-\phi)=m'(T'-\theta'). \quad (2)$$

The only two unknowns are x and s', which we can find by solving the two simultaneous equations.

Determine as above the heat of fusion of Beeswax.

40. Determination of the heat of vaporisation of Water.
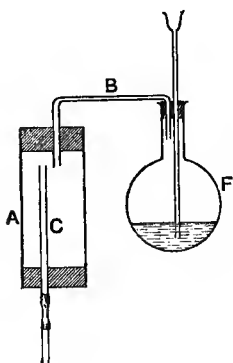
[F is a flask about 300 cubic cm. capacity, through the cork of which pass a thistle funnel and one end of a tube B bent twice at right angles, as in the figure. The other end of B fits into a hole of a cork closing one end of a piece of wide glass-tubing A, 8 to 10 cm. in length and 2.5 cm. in diameter. The other end of A is also tightly closed with a cork, through which passes a piece of glass-tubing C, the upper end of which is above the level of the end of the tube B, and its lower end is connected by a piece of india-rubber tubing to another short piece of glass tubing.]

Fig. 11.

Apparatus (Fig. 11). Calorimeter: Thermometer: Bunsen Burner.

Experiment. Fill the flask half full of water, and heat to boiling. Counterpoise a calorimeter and fill it two-thirds full

of water. Weigh to determine mass, m, of water. When the steam has been coming off freely from the delivery tube, note the temperature, t, of the water in the calorimeter and let the delivery tube dip under its surface. Allow the steam to pass into the water, keeping it well stirred until the temperature has risen about 70°. Pinch the india-rubber connecting tube and take the delivery tube out of the water and note the final temperature, θ, to which the thermometer rises. Weigh the calorimeter and determine the mass, M, of steam condensed. Note barometric height and determine the temperature, T, of the boiling water. The calorimeter and the cold water have risen from $t°$ to $\theta°$, therefore have absorbed $(m + \mu)(\theta - t)$ calories [33]. The condensed steam has cooled from $T°$ to $\theta°$, giving out $M(T - \theta)$ calories, therefore the amount of heat given out by M grams of steam condensing to water at $T°$ is $(m + \mu)(\theta - t) - M(T - \theta)$. The amount that one gram of steam gives out on condensing to water at $T°$ is therefore

$$\frac{(m + \mu)(\theta - t) - M(T - \theta)}{M},$$

which is the required heat of vaporisation of water.

41. Determination of the heat of vaporisation of alcohol.

Apparatus. Same as in Experiment 40 with addition of Alcohol.

Experiment. As alcohol mixed with water emits heat we must pass the vapour into alcohol instead of into water. Fill the flask half full of alcohol and raise it to its known boiling point T. Fill the calorimeter half full of alcohol and determine the mass, M, introduced, and also its temperature, t. Proceeding in a similar way as in Experiment 40 we pass the vapour into the alcohol and note the final temperature, θ, and determine the mass, M, of alcohol vapour condensed. Then, if s is the known specific heat of alcohol and x is latent heat, we have

$$Mx + Ms(T - \theta) = (ms + \mu)(\theta - t),$$

whence we can determine x, the heat of vaporisation required. Determine as above the heat of vaporisation of Turpentine.

[33] See Note 25.

D. EVAPORATION.

*42. Determination of the vapour tension of Alcohol.
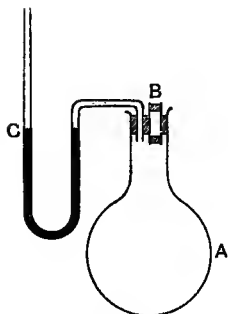
[*A*, a flask of about 300 c.c. capacity with rather a wide neck, is fitted with an air-tight cork. Through this passes one end of a U-tube *C* about ·5 cm. in diameter, bent as in the figure, the longer limb of which is about 30 cm., the shorter about 15 cm. in length. Through the cork also passes a piece of wide glass-tubing *B* about 6 cm. in length and 75 cm. in diameter, the ends of which are closed by smooth plugs of cork [34].]

Apparatus (Fig. 12). Beaker : Thermometer : Metre Scale : Bunsen Burner : Alcohol : Curve-paper.

Fig. 12.

Experiment. Pour into the tube *C* sufficient clean mercury to fill it nearly to the level of the horizontal branch. Fit it to the cork, and fit the cork tightly into the flask. Place the flask in a beaker of water on a sand-bath and note the temperature, t_1. Read off the difference of levels, if any, h, of the mercury, and note the barometric pressure, H. The pressure of the air in the flask is $H \pm h$, according as the level in the shorter arm is below or above that in the longer arm. Let this pressure be P_1. The next step will be to introduce some alcohol into the flask without opening any communication with the external air. To do this take out the upper plug from the tube *B* and nearly fill the latter with alcohol. Replace the plug and push it down the tube. As the alcohol is compressed it will force out the lower plug and drop into the flask and will saturate the space with its vapour. Read off the difference of levels of the mercury h_1. Then $H + h_1$ gives us the pressure of the alcohol vapour and air at t_1. Therefore $h_1 - h$ is the pressure, p, due to the alcohol alone. Heat the water

[34] The plugs cut out by the usual cork-borers in making holes through a cork will do very well, if smoothly cut.

gradually, keeping it well stirred until the thermometer rises about $5°$. Read the temperature, t_2, and the difference of levels, h_2 [35]. Then $H + h_2$ gives the pressure of the alcohol-vapour and air. Continue heating and reading the thermometer and difference of levels for every $5°$ rise of temperature until the thermometer marks $50°$. Enter your results in a tabular form as follows :—

Barometric height, $H = \ldots$ mm.

Temperature.	Difference of levels.	Pressure of alcohol + air.	Pressure of air.	Pressure of alcohol.
t_1	h_1	$H + h_1$	P_1	p_1
t_2	h_2	$H + h_2$	P_2	p_2
t_3	h_3	$H + h_3$	P_3	p_3
...	...	...	...	...

To get the pressure due to the alcohol alone we must subtract from the numbers in the third column the corresponding pressures due to the air, entered in the fourth column. To get them, let us find P_3. For every degree rise in temperature the pressure of the air increases by $\frac{1}{273}$rd of its original pressure [36], i. e. by $\cdot00366\, P_1$. On the temperature rising from $t°_1$ to $t°_3$ the pressure P_1 becomes $P_1\,[1 + \cdot00366\,(t_3 - t_1)]$, which is P_3.

Plot a curve, taking the temperatures as abscissae, and the corresponding vapour-pressures of alcohol as ordinates.

Determine as above the vapour-pressure of Turpentine.

43. Determination of the pressure of aqueous vapour at temperatures below 100°.

[Take a thick glass tube A closed at one end about 50 cm. in length and ·75 cm. in diameter. To the other end attach a piece of thick india-rubber tubing [37] R about 50 cm. long, and fill both glass and rubber-tubing with clean dry mercury up to within about 2 cm. of the open end. Fill the empty part with distilled water. Pinch the india-rubber tube, and raise the glass tube so that the water passes to the closed end, being careful that no

[35] See Note 17.

[36] For the small range of temperatures we can use this approximation instead of the true increase, viz. $\frac{1}{273}$rd of its original pressure at $0°$.

[37] Thick india-rubber tubing lined with canvas ought to be used, to withstand the pressure.

air-bubbles pass up as well. Fit on another tube B about a metre in
length to the india-rubber tubing and pour in a little more mercury. Pass
the closed end of A through a cork fitting tightly into the neck of a
deflagrating jar about 9 cm. in diameter at the broad end (Appendix B. 6).
Make a mark at 'a' about 2·5 cm. from the closed end of A. This
apparatus should be attached to a wooden support by leather bands.
It would be more convenient to replace the india-rubber tubing by a
T-tube and india-rubber ball as described under Fig. 9.]

Fig. 13.

Apparatus (Fig. 13). Thermometer:
Boiling Can: Metre Rule: Bunsen
Burner: Curve-paper.

Experiment. Nearly fill the jar C
with water and place a delivery tube in
it so that it reaches nearly to the bottom.
Connect this tube with the boiling can
so that steam may be passed into the
water contained in C. Place a thermo-
meter in C with its bulb near the closed
end of the tube A. Raise or lower the
tube B [38] so that the level of the mercury
may reach the mark a. Read the tem-
perature of the water t_1 and also the
difference of levels of the mercury in the
two tubes h_1. Note the barometric pres-
sure H. The pressure of the vapour of
the water in the closed tube is therefore
$H - h_1$. Pass steam into the jar C until
the temperature rises about 5°. The
pressure of the water-vapour increases
and will push the mercury below a.
Bring the level of the mercury back to a
by raising the tube B. Take the de-
livery tube out of C and stir the water,
and read the temperature, t_2, when it has become stationary.
Readjust the level of the mercury to the mark a and read the
difference of levels h_2. Repeat this, raising the temperature
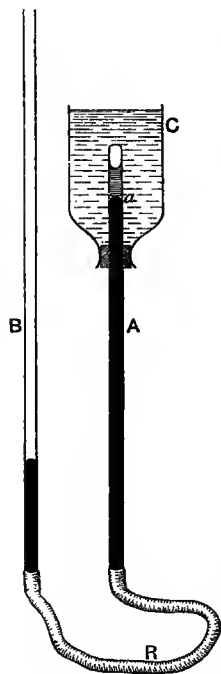
[38] If we replace the india-rubber tube by the india-rubber ball we must
alter height by pressure on it.

each time about $5°$ until the water boils, and enter your results in a tabular form as follows:—

Temperatures.	Difference of levels.	Pressure of vapour.
t_1	h_1	$H-h_1$
t_2	h_2	$H-h_2$
...	...	...

Barometric height, $H = ...$mm.

Plot your results in a curve, taking the temperatures as abscissae and the corresponding pressures as ordinates.

N.B. To obtain a more accurate result we ought to allow for the fact that the upper portion of the mercury column of A which is immersed in the water is at a higher temperature than the rest of the mercury. Suppose at any given excess of temperature τ the difference of levels between A and B is h, of which the length h' is outside and h'' in the water. If δ is the mean coefficient of absolute expansion of mercury at $\tau°$, h'' would become $\dfrac{h''}{1+\delta\tau}$ when reduced to the temperature of the room, therefore the corrected difference of level would be

$$h' + \frac{h''}{1+\delta\tau} = h' + h''(1-\delta\tau) \text{ approximately,}$$
$$= h' + h'' - h''\delta\tau = h - h''\delta\tau.$$

We should have therefore to subtract from the numbers in the second column a length obtained by multiplying the height of ' a ' above the cork by δ, and by the corresponding excess of the temperature of the water above the room.

44. Determination of the pressure of aqueous vapour at temperatures above 100°.

Apparatus. Round-bottomed flask fitted with a two-holed bung: Glass tubing 50 cm. long: Narrow Glass Jar about 30 cm. high: Thermometer: Retort-stand: Bunsen Burner: Mercury: Curve-paper.

Experiment. Bend the glass tube at right angles about 5 cm. from one end. Ten centimetres from this bend, bend it again at right angles in same direction. Fit the shorter limb into a hole of the bung : into the other hole push the thermometer so that its bulb nearly touches the surface of the water with which the flask is half filled. Put in the flask a small piece of clean coke to prevent boiling with bumping. Tie down the bung to prevent its being forced out by the pressure of the steam. Place the flask on a sand-bath on a ring of the retort-stand at a convenient height. Arrange the lower end of the bent tube so that it nearly touches the bottom of the gas jar. Boil the water, and noting the barometric height, H, find the temperature, T, at which it boils. Pour into the jar some mercury until its level is about 2 cm. from the bottom. The tube should touch the side of the jar so that its end may be seen through the glass. Heat the water again until it boils [39]. Note the temperature T_1, and measure the distance h_1 of the surface of the mercury above the open end of the tube. The temperature, T_1, is the boiling point under a pressure $H + h_1$. Repeat this process, adding nearly equal quantities of mercury each time. Enter your results in a tabular form as follows :—

Barometric height, $H = \dots$ mm.

Boiling points.	Heights of mercury above end of tube.	Pressures.
T	0	H
T_1	h_1	$H + h_1$
T_2	h_2	$H + h_2$
...	...	...

Plot a curve, taking the boiling points as abscissae, and corresponding pressures as ordinates.

---

[39] If a considerable quantity of steam condenses on the mercury it may be occasionally got rid of by means of a large pipette.

45. Determine by Regnault's Hygrometer (*a*) **the pressure of the vapour in the air;** (*b*) **the relative humidity of the air.**

[Take a boiling tube *A* from 2 to 3 cm. in diameter and silver the bottom of it as described in Appendix B. 8. Through a cork fitting this tube pass a thermometer *T* and two elbow-tubes *B* and *C*, one of which reaches almost to the bottom of the boiling tube.]

Apparatus (Fig. 14). Aspirator.

Experiment. Pour some ether into the Hygrometer so as to cover the bulb of the thermometer when the cork is replaced. Attach the elbow-tube *B* to an aspirator. As the water flows out of the latter, air, entering the tube *C*, bubbles through the ether, which therefore evaporates quickly. The external air is in consequence cooled and its temperature is lowered to a point at which it can no longer contain the vapour

Fig. 14.

existing in it. Therefore the vapour will condense, and at this temperature (called the '*dew-point*') it will exert its maximum pressure. Read the temperature by the thermometer *T*, at which the metal surface begins to be dimmed [40] by the condensation of vapour. Stop the aspirator and read the temperature at which the dimness disappears. The average of the two readings will give the dew-point approximately. Pass air through the ether again, and stop when the thermometer is two degrees above the approximate dew-point just found. Then aspirate slowly, and stop every half degree watching for a deposit of vapour. By this means a more correct value of the dew-point is obtained [41]. Look in the tables for the maximum
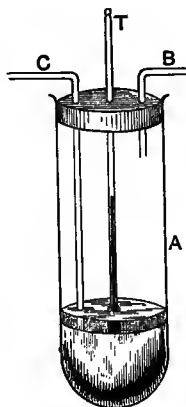
[40] It will assist in the detection of this film if, when its appearance is suspected, a small part of the surface is wiped with a camel's hair brush, or a momentary touch of the finger. If any dew is there, it will be wiped away, and the contrast between the wiped portion and the rest of the surface will be clearly seen.

[41] It is necessary that the observer should stand as far away from the instrument as possible, so that the radiation from his body should not affect the result.

E

pressure f of water vapour at this temperature, which gives us the pressure of the vapour in the air.

The humidity of the air is the ratio of the mass of vapour present in a certain volume of the air to the mass of vapour this volume could contain if saturated at the existing temperature. This ratio can be proved to be the same as $\dfrac{f}{F}$, where f is the vapour-tension in the air (above found), and F the maximum tension of vapour at the temperature of the air. The latter is found also by referring to the tables [Appendix. A. 10]. The percentage humidity is given by $\dfrac{f}{F} \times 100$.

46. Determination of the constant of a wet and dry bulb Hygrometer.

Apparatus. Two thermometers : Vessel of water.

Experiment. Hang the two thermometers about 10 cm. apart from one another. Cover the bulb of one with fine muslin, to which is attached a piece of loose cotton thread (such as is used for the wick of an oil-lamp) long enough to dip into the small vessel of water[42]. The muslin and cotton are to begin with thoroughly wetted with distilled water, then the water from the cistern rises up the thread by capillary action, and the bulb is thus kept constantly wet.

The two thermometers and small vessel of water ought to be fixed to a wooden support and hung on the wall of the laboratory in a permanent position.

In consequence of the continual evaporation the temperature of the wet-bulb thermometer is always lower than that of the dry-bulb thermometer. It is proved in books on physics that

if t is the temperature of the dry-bulb thermometer,

t' the temperature of the wet-bulb thermometer,

F' the maximum pressure of water vapour at temperature t',

---

[42] The muslin and lamp cotton should, before use, be boiled in water containing a little washing soda to get rid of grease.

f the pressure of the water vapour in the air,

and H the barometric height,

then $f = F' - AH (t - t')$, where A is the '*constant*' of this instrument.

To determine A, read t, t', and the barometric height H. Look in tables for F', and find f by Regnault's Hygrometer (Experiment 45). Substitute their values in the above equation, and so determine A.

Having once determined A for the particular position in which the instrument is always in future to be used, we can evidently determine f, the vapour pressure in the air, by reading the dry and wet-bulb thermometers and the barometric height, and finding the value of F' from the tables.

*47. Determination of the mass of 1 litre of Laboratory air by reading the barometer, thermometer and hygrometer.

Apparatus. Thermometer: Hygrometer.

Experiment. The mass of a litre of laboratory air equals the mass of the dry air added to the mass of the vapour contained in it at the existing temperature and pressure.

Read the temperature t of the air, and the barometric height H, and determine by Regnault's Hygrometer the pressure, f, of the vapour in the air.

i. *To determine the mass of a litre of dry air.*

The dry air is at the temperature t and under a pressure $H - f$. When reduced to $0°$ and 760 mm. this volume becomes

$$\frac{H-f}{760} \times \frac{273}{273+t} \text{ litres.}$$

The mass of 1 litre of dry air at $0°$ and 760 mm. is 1·293 grams, therefore the mass of the above is

$$m_1 = \frac{H-f}{760} \times \frac{273}{273+t} \times 1·293 \text{ grams.} \qquad \text{(i)}$$

ii. *To determine the mass of a litre of vapour.*

Reduced to $0°$ and 760 mm. this volume of vapour, which is

at temperature t and pressure f, becomes

$$\frac{f}{760} \times \frac{273}{273+t} \text{ litres,}$$

and since the density of water vapour is $\frac{5}{8}$ths of dry air, the mass of the above vapour is

$$m_2 = \frac{f}{760} \times \frac{273}{273+t} \times \frac{5}{8} \times 1\cdot293 \text{ grams.} \quad \text{(ii)}$$

Adding (i) and (ii) together, we get for the mass of a litre of the laboratory air,

$$M = m_1 + m_2 = \frac{H - \frac{3}{8}f}{760} \times \frac{273}{273+t} \times 1\cdot293 \text{ grams.}$$

Substituting for H, f, t we get M, the mass required.

E. RADIATION.

48. To investigate Newton's Law of cooling.

Apparatus. Tin vessel about 200 c.c. capacity : Large Beaker : Thermometer : Bunsen Burner : Curve-paper.

Experiment. Newton stated that when a heated body cooled in an enclosure of constant temperature, its velocity of cooling is proportional to its excess of temperature over that of the enclosure. Let us take a thermometer as the body to be heated and allowed to cool. In order to keep the temperature of the enclosure constant take the tin vessel and float it in a large beaker of water, so that the water level is about 2 cm. from the top of the vessel on the outside—sand or shot may be used as ballast. Take a piece of wood to be used as a cover, bore a hole in the middle of it, and fit a cork, through which the thermometer passes, to the hole. Take out the thermometer and heat it carefully to about 70° or 80° in the hot air rising from a flame. Replace it in the cork and arrange the cover so that the thermometer dips into the empty tin vessel. Note the

temperature every half minute as it cools down to the temperature of the room, and enter your results as follows :—

Temperature of the enclosure t ...

Observed temperature.	Excess of temperature.	Average excess every half minute.	Fall in degrees every half minute.	Average excess. Fall.
t_1 t_2	θ_1 θ_2	$\dfrac{\theta_1 + \theta_2}{2}$	$t_1 - t_2$	...
t_3	θ_3	$\dfrac{\theta_2 + \theta_3}{2}$	$t_2 - t_3$	...
...	...	...	...	...

The numbers in the second column are obtained by subtracting the temperature t of the water in the beaker from each of those in the first column.

The numbers in the third column are the average of successive pairs of numbers in the second column.

The numbers in the fourth column are the differences between successive pairs in the first column.

The numbers in the fifth column are the quotients of corresponding numbers in the third and fourth columns.

If Newton's Law were true this last series would be constant. It will be found, however, that as the temperature decreases the numbers increase somewhat, which shows that Newton's Law is not quite exact.

Plot your results in a curve, taking the fall in degrees every half-minute as abscissae, and the corresponding average excesses as ordinates.

49. To plot the curve of cooling for a calorimeter and to determine how much heat is radiated in unit time from it at a given temperature.

Apparatus. Calorimeter: Thermometer: Bunsen Burner: Curve-paper.

Experiment. Counterpoise the calorimeter. Boil some water

in a beaker, and pour some of it into the calorimeter so as to very nearly fill it. Support a thermometer so that its bulb is immersed under the surface of the hot water, and observe the temperatures every half minute as the calorimeter cools to the temperature of the room. At the end weigh the calorimeter and find the mass, m, of water introduced.

Enter your results in a tabular form, and plot them on a curve, taking the times as abscissae and the corresponding temperatures as ordinates. This curve is called the *cooling curve* for the calorimeter. It is independent of the nature of the liquid contained in it. (Experiment 35.)

To determine the quantity of heat radiated in unit time at a certain temperature, say at 50°. Through the point on the temperature axis corresponding to 50° draw a horizontal straight line cutting the curve at the point P. Through P draw a tangent to the curve and continue it to cut both axes. The tangent of the angle this tangent makes with the time-axis evidently gives us the rate of cooling at 50°. Let the tangent cut the temperature axis at a point corresponding to a temperature T, and the time axis at a point corresponding to N half-minutes. Then at 50° it would cool $T°$ in N half-minutes, therefore $\dfrac{T°}{N}$ in one half-minute. The quantity of heat radiated depends on the mass and nature of the liquid in the calorimeter. If m is the mass of water, and μ the water value of the calorimeter, the quantity of heat given off at 50° during the half-minute is evidently $(m+\mu)\dfrac{T}{N}$

If we had filled the calorimeter with a mass m of another liquid we should have to substitute ms in the above for m, where s is the specific heat of the liquid.

Determine as above the quantity of heat radiated off by (1) water, and (2) mercury at 40° from the same calorimeter.

The *emissive power* of a substance is that quantity of heat ‹ ‹ ‹

emitted normally from unit area in unit time when its excess of temperature is $1°$ above that of the enclosure.

*50. To compare the emissive power of two substances, e. g. Lampblack and Tinfoil.

Apparatus. Two vessels of as nearly the same size and shape as possible [43]: Thermometer: Beaker: Bunsen Burner: Curve-paper.

Experiment. Cover the outside of one vessel with lampblack by holding it in an ordinary gas flame. Fill it nearly with boiling water and arrange the thermometer with its bulb immersed in the water. Plot the cooling curve as in Experiment 49. Now cover the outside of the other vessel to the same height with strips of tinfoil, and plot its cooling curve on the same piece of curve-paper, being careful that the water is at the same height as in the first case. The emissive powers of lampblack and tinfoil are evidently in the same proportion as the quantities of heat emitted in unit time at the same temperature from equal surfaces, i.e. in this case as their rates of cooling. Determine, as in Experiment 49, their rates of cooling at various temperatures, and arrange results as follows:—

Tempera-tures.	(1) $\dfrac{T}{N}$	(2) $\dfrac{T'}{N'}$	(1) $\div$ (2) $\dfrac{E}{E'}$
t_1	...	...	...
t_2	...	...	...
...	...	...	...

Plot a curve, taking the numbers in the second column as abscissae and those in the third column as ordinates.

Compare the emissive powers of varnish, white lead, paper.

---

[43] Small conical flasks of about 80 c.c. do very well.

APPENDIX A.

(1) Volume of unit mass and density of water at different temperatures.			(2) Volume of 1 c.c. at 0° and density of mercury at different temperatures.	
$t°$ C.	Volume of unit mass.	Density.	Volume of 1 c.c. at 0°.	Density.
0	1·0001	0·99988	1·0000	13·596
4	1·0000	1·00000	1·0007	13·586
10	1·0003	·99976	1·0018	13·572
15	1·0008	·99917	1·0027	13·559
20	1·0017	·99827	1·0036	13·547
25	1·0029	·99713	1·0045	13·535
30	1·0043	·99578	1·0054	13·523
35	1·0059	·99407	1·0063	13·511
40	1·0077	·99236	1·0072	13·499
45	1·0097	·99029	1·0081	13·487
50	1·0120	·98821	1·0090	13·474
55	1·0144	·98580	1·0099	13·462
60	1·0169	·98339	1·0108	13·450
65	1·0197	·98067	1·0117	13·438
70	1·0226	·97795	1·0127	13·426
75	1·0257	·97495	1·0136	13·414
80	1·0289	·97195	1·0145	13·401
85	1·0322	·96876	1·0154	13·389
90	1·0357	·96557	1·0163	13·377
95	1·0394	·96212	1·0172	13·365
100	1·0432	·95866	1·0182	13·353

(3) *Densities.*

Lead	11·4
Iron	7·76
Copper	8·95
Glycerine	1·26

(4) *Coefficients of Expansion* (*absolute*).

Glass (cub.)	?·000026
Zinc (lin.)	·000029
Copper (lin.)	·000016
Brass (lin.)	·000019
Iron (lin.)	·000012
Amyl Alcohol (cub.) . .	·00109
Glycerine (cub.) . . .	·000526
Turpentine (cub.) . . .	·00105
Air (cub.)	·00366

(5) *Melting points.*

Paraffin-wax	45°
Beeswax	62°
Stearic Acid	69·9°
Benzoic Acid	121°
Tin	235°
Lead	335°

(6) *Boiling points.*

Methyl Alcohol	66·3°
Benzol	80·4°
Turpentine	156°
Ether	35·5°
Carbon Bisulphide . . .	48°

(7) *Specific Heats.*

Sulphur	.234
Beeswax	.64
Zinc	.0935
Iron	.112
Lead	.0315
Copper	.095
Ethyl Alcohol	.615
Glycerine	.555
Turpentine	.467
Mercury	.0333
Sulphuric Acid	.33
Paraffin-wax	.683

(8) *Heats of fusion.*

Ice	79.25
Beeswax	97.22

(9) *Heats of vaporisation under a pressure of 760 mm. of mercury.*

Water	536
Methyl Alcohol	264
Turpentine	69

(10) *Maximum pressure of aqueous vapour in mm. of Mercury.*

$t°$		$t°$		$t°$		$t°$		$t°$		$t°$	
0	4.6	11	9.79	22	19.66	45	71.39	99	733.21	100.1	762.73
1	4.94	12	10.46	23	20.89	50	91.98	99.1	735.85	100.2	765.46
2	5.30	13	11.16	24	22.18	55	117.48	99.2	738.50	100.3	768.20
3	5.69	14	11.91	25	23.55	60	148.79	99.3	741.16	100.4	771.95
4	6.10	15	12.70	26	24.99	65	186.94	99.4	743.83	100.5	773.71
5	6.53	16	13.54	27	26.51	70	233.08	99.5	746.50	100.6	776.48
6	7.00	17	14.42	28	28.10	75	288.50	99.6	749.18	100.7	779.26
7	7.49	18	15.36	29	29.78	80	354.62	99.7	751.87	100.8	782.04
8	8.02	19	16.35	30	31.55	85	433.00	99.8	754.57	100.9	784.83
9	8.57	20	17.39	35	41.83	90	525.39	99.9	757.28	101	787.59
10	9.17	21	18.50	40	54.91	95	633.69	100	760.00	105	906.41

(11) *Conversion Tables.*

1 centimetre	= .39 inch.		1 inch	= 2.54 centimetres.
1 sq. centimetre	= .155 sq. inch.		1 sq. inch	= 6.45 sq. centimetres.
1 cub. centimetre	= .061 cub. inch.		1 cub. inch	= 16.386 cub. centimetres.
1 gram	= 15.432 grains.		1 grain	= .065 gram.
1 kilogram	= 2.2 lbs.		1 lb.	= 453.593 grams.

If $t°$, $θ°$ represent the same temperature on the Centigrade and Fahrenheit thermometers respectively,

$$θ = \tfrac{9}{5}t + 32; \qquad t = \tfrac{5}{9}(θ - 32).$$

At 39°F or 4°C a cubic foot of water weighs nearly as much as 62.4 lbs. At the same temperature 1 cub. cm. of water weighs as much as 1 gram.

Appendix B.

1. Probable Error. When all the results of an experiment are equally trustworthy, the probable value of the required result is found by adding them together and dividing by the number of the results, i.e. by finding their arithmetical mean. Let n be the number of results

$\delta_1, \delta_2, \delta_3,$ &c. = their differences,

$\qquad S = \delta_1{}^2 + \delta_2{}^2 + \delta_3{}^2 + \dots$ or the sum of their squares,

then it can be proved that the probable error of the final result is

$$= \pm\, 0.6745 \sqrt{\frac{S}{n\,(n-1)}}.$$

2. To graduate and calibrate a glass bulb-tube and to fill it with a liquid.

(*a*) To graduate it cover the whole of the stem with a uniform thin layer of paraffin-wax. Fix it along a metre scale, and with a fine needle make a scratch at intervals of ·5 cm., and scratch the numbers of every fifth division [44]. Brush some solution of Hydrofluoric Acid over the tube and leave it for ten minutes. The acid will etch the glass where it is exposed. Finally melt off the wax and dissolve any that remains with ether.

(*b*) To calibrate it weigh the empty bulb-tube. Place it with its open end under some clean dry mercury, and by driving out the air by heat fill the tube partly with the mercury, and allow it to cool to the temperature of the room. Suppose the mercury reaches to the nth division on the stem. Weigh again and determine the mass, M, of the mercury it contains. The volume of the bulb and the n divisions is $\dfrac{M}{\sigma}$ c.c., where σ is the density of mercury at the temperature of the room. Therefore if B is the volume of the bulb [up to the point where the divisions begin] and v the volume of one division,

$$B + nv = \frac{M}{\sigma}.$$

---

[44] We suppose the tube to be of uniform bore.

Now introduce as before some more mercury, say up to the mth division, and find the total mass, M', of the mercury contained in the tube. Now we have

$$B + mv = \frac{M'}{\sigma}.$$

From the above two equations we can find the volume B of the bulb and v the volume of each division of the stem.

(*c*) A convenient method of filling the bulb-tube is to support it vertically. Connect the top of the stem by a short piece of india-rubber tubing with a large funnel resting in a ring of a retort-stand. Fill the funnel with liquid and heat the bulb carefully with a burner. By this means the air is expelled and the liquid can be made to fill the tube.

3. To graduate and calibrate a glass tube. Take a narrow strip of gummed paper as long as the tube to be graduated and mark off along it divisions ·5 cm. apart. Stick the paper along the tube. Take a short piece of the same glass-tubing and smooth its ends flat on sand paper. Measure its length, *l*. Counterpoise a crucible. Place the tube horizontally under the surface of some clean mercury so that it may be filled with it. Close the two ends by the fingers and take the tube out of the mercury and transfer the mercury it contains to the crucible. Weigh and find the mass, *m*, of the mercury. Read the temperature, *t*, of the room. Find from the tables the density σ of mercury at this temperature. Then $\frac{m}{\sigma}$ is volume of a length *l* cm. of the tube, therefore the volume of each of the divisions on the graduated tube is $\frac{m}{2l\sigma}$ cubic cm.

4. To clean and dry glass vessels. Rinse them out successively with (1) Nitric Acid, (2) Distilled Water, (3) Caustic Potash, (4) Distilled Water, (5) Alcohol. To dry them take a piece of hard glass tube about 20 cm. long and 1 cm. in diameter. Draw out one end so that it may be sufficiently small to insert in the vessel. Bend the tube at right angles about 5 cm. from this end. Fix tube in a

clamp with bent end vertical, and allow the horizontal portion
to be heated by a large Bunsen. By means of india-rubber
tubing attached to the larger end of the glass tube and to a pair
of bellows, cause a gentle current of hot air to pass into the
bottle, which must be placed resting mouth downwards on the
upright portion of the glass tube. A very useful piece of
apparatus for this and other purposes is the hand-bellows sold
by chemists to be used with a throat spray.

5. To clean mercury. A piece of clean writing paper is
folded twice at right angles and then opened out in the form of
a cone ; it is then fitted into a glass funnel. A few holes are
made with a fine needle near the apex of the paper cone, so
that when mercury is poured in the liquid escapes through these
in fine streams. Mercury filtered in this way is quite free from
dust. Another method is to pour the mercury into a handkerchief
and press it through the interstices of the linen.

6. To make a cork water-tight. Soak the cork thoroughly
in water and then place it in oil, and heat to about 120°.

7. Black Varnish. A good dead black varnish for radia-
tion experiments may be made by putting 2 grams of lamp-
black (or 'vegetable black') into a mortar, weighing into the
vessel 8 grams of gold size, grinding the whole together into
a smooth paste and adding 10 grams of turpentine. The whole
must be stirred thoroughly together just before use, and laid on
evenly with a soft brush. It adheres better if the surface is
slightly warmed previously, and heated more strongly after the
coating is applied.

8. Silvering Solution. Make two solutions as follows :—

(*a*) Two grams of silver nitrate are dissolved in 16 c.c. of
distilled water ; to this ammonia is added until the precipitate
first thrown down is almost entirely re-dissolved. The solution
is filtered and diluted to 200 c.c.

(*b*) Two grams of silver nitrate are dissolved in a little
distilled water and this is poured into a litre of rapidly boiling
distilled water. 1·66 gram of Rochelle salt (Potassium Sodium

Tartrate) is added, and the mixture boiled for a short time till the precipitate contained in it becomes grey. This is then filtered while hot. The boiling tube to be silvered has to be thoroughly cleaned inside with (1) Nitric Acid, (2) Distilled Water, (3) Caustic Potash, (4) Distilled Water, (5) Alcohol, (6) Distilled Water. Equal volumes of the above solutions are mixed together and poured into the boiling tube up to the level required to be silvered. In about an hour the silvering will be complete. Pour off the exhausted liquid, rinse out with distilled water. Throughout the whole operation the most scrupulous cleanliness is absolutely essential.

9. **Curves and Curve paper.** Paper ruled in centimetres and millimetres can be obtained from Messrs. Williams and Norgate and Waterlow and Sons. The observed points of the curve may be marked with small dots made with a hard sharp pencil, and these may be marked by small crosses. In drawing the curve the successive points may be first joined by thin straight lines, and a smooth curve then drawn through them in a freehand manner [see Note 5].

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